A Computerized Pitch-Perception Training Program for the Hearing Impaired

by

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DECLARATION

The material presented in this thesis is the original work of the candidate except as acknowledged in the text, and has not been previously submitted, either in part or in whole, for a degree at this or any other University.

D. M. P. Jayakody

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ABSTRACT

Pitch perception plays an important role in both music and speech perception. Technological advancements in both hearing aids and cochlear implants (CIs) have helped to improve the speech perception abilities of the hearing impaired. However, pitch-related speech and music perception tasks remain a challenge to both hearing aid users and CI recipients. Existing research suggests that auditory training may be useful for enhancing these perceptual skills.

This research developed a computerized pitch-perception training program and evaluated its effectiveness for improving the pitch-related speech and music perception skills of postlingually deafened adult CI recipients (CIA), postlingually hearing impaired adult hearing aid users (HA), and prelingually deafened pediatric CI recipients (CIC). The training program consisted of interactive listening activities using ‘real world’ natural musical instrument sounds and sung vowels. Two versions of the training program were developed, including the Version One training (V1T), which employed a fixed level approach and the Version Two training (V2T), which used an adaptive level approach. The training groups included 10 HA, eight CIA, and three CIC participants for V1T and seven HA, eight CIA, and two CIC participants for V2T. The normal hearing control groups included 19 normal hearing adults (NHA) and 12 normal hearing children (NHC). The training groups completed 10 weeks of training at home using the computerized pitch-perception training program. Both training and control groups undertook objective tests on various aspects of pitch-related speech and music perception before and after the training period. In addition, questionnaires were used to obtain the background information related to the participants’ music listening experiences. The training group also filled out a post-training evaluation questionnaire regarding their opinions about the efficacy of the training program. For the CIC group, some

parts of the questionnaires were filled out by parents of the CIC participants only and some parts by both of the CIC participants and their parents.

The results revealed that both CIA and HA groups showed an improvement following training with either V1T or V2T. However, V2T generally resulted in greater improvements than V1T. The pitch perception training from both versions of the program seems to have generalized to the performance of some pitch-related speech and music perception tasks. For both HA and CIA training groups, a statistically significant training effect on pitch-related speech and music perception test scores was observed ($p < 0.05$). A general improvement in the subjective perception of the trainees' abilities in performing the pitch-related speech and music tasks was also observed. The CIC training groups failed to show a significant improvement in any of the perceptual tasks except for the CNC-phoneme test.

Overall, more challenging tasks, especially tasks that required more focused attention, resulted in a more noticeable training effect than easy tasks. Results from the subjective evaluation carried out through a post-training evaluation questionnaire generally agreed with the improvements observed in the objective tests. Based on these findings and the feedback from the participants regarding the training program, a final version of the program is being formalized.

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CHAPTER 1: INTRODUCTION

Pitch is defined as "that attribute of auditory sensation in which sounds may be ordered on a scale extending from low to high. Pitch depends on frequency content, sound pressure and the waveform of the stimulus" (ANSI, 1994). It is a subjective, psychophysical attribute of frequency that is applicable to both music and speech (Yost, 2007). For non-tonal language speakers (e.g., English speakers), accurate pitch perception assists with understanding paralinguistic functions of language, such as age, sex, emotional states of the speaker, dialect, and prosody (Luo et al., 2007; Peters, 2006; Shinall, 2005). For tonal languages, variations in pitch (e.g., height and contour of a tone) provide phonemic information as well as serving the paralinguistic functions. The differing roles of pitch information in different phonological systems can impact on speech perception accuracy (Wei, Cao, & Zeng, 2004).

Musical pitch is an "attribute of auditory sensation in which sounds may be ordered on a musical scale" (ASA, 1960). In music, pitch is important to perceive the chords, intervals and melodies produced by most of the musical instruments (Yost, 2007). Music serves as an aid in relaxation, and/or reminiscence or socialization. The ability to listen to music, learn a musical instrument, and participate in music-related activities such as singing, karaoke, dancing to music, going to concerts or the cinema, or watching TV programs can impact on one's social life. Not being able to participate in these activities could have a negative impact on one's quality of life (QOL) and could be isolating.

As pitch is fundamental to music, the inability to correctly perceive pitch information may affect one's QOL. The World Health Organization defines QOL as an "individual's perceptions of their life in the context of the culture and the value systems where they live, and in relation to their goals, expectations, standards, and concerns" (WHO, 1997). About 4.9% of New Zealanders aged 15-64 years and 22.1% over 65 years are reported to have a hearing loss causing disability (Greville, 2005). The ability to communicate effectively is considered a major component of QOL. The most common problem faced by hearing impaired adults is reportedly the difficulty in understanding conversations (Davis, 1989). In 2001, the WHO subdivided a list of everyday activities engaged in by people of all ages into nine domains. Out of these nine domains, six (i.e., communication, interpersonal relationships, learning and applying knowledge, self-care, domestic life, and major life areas) rely on effective communication. Difficulties faced by the hearing impaired limit their participation in activities in these domains, affecting their QOL.

There is a lack of research investigating music perception for hearing aid and cochlear implant (CI) users. The majority of postlingually deafened adult CI recipients demonstrate excellent open-set speech discrimination in quiet (Fetterman & Domico, 2002). However, speech perception in noise, perception of tonal languages, and music perception remain challenging for many CI recipients (Fetterman & Domico, 2002; Galvin et al., 2007; Gfeller et al., 2007; Grasmeder & Lutman, 2006; Kong et al., 2004a; Looi 2008b; McDermott, 2004; Turner et al., 2004). The difficulty CI recipients experience in perceiving more complex acoustic stimuli is partly due to the limitations in pitch perception (Wei et al., 2004; Xu et al., 2004). Prelingually deafened children using CIs have shown improved performances in music perception with training (Abdi et al., 2001; Blumberg et al., 2006). To date, however, few studies have evaluated the treatment efficacy of a training program for teaching musical skills to children with CIs (McDermott, 2004). Studies by Gfeller et al. (2000a) and Galvin et al. (2007) suggest that some aspects of music listening can be improved with training, even with current-day technology.

The present study aims to address some of the above-mentioned issues, by developing a pitch perception training program to improve the pitch-related speech and music perception skills of the hearing impaired. Once developed, the program was pilot tested on postlingually deafened CI and hearing aid users and prelingually deafened children using CIs. There are only a few music training programs that are currently available for CI recipients (Abdi et al., 2001; Gfeller et al., 2002b; Gfeller et al., 1999). The current program differs from existing training programs as it covers a large range of frequencies and uses natural recordings of both male and female sung vowels as well as 13 commonly used musical instruments (i.e., Violin, Cello, Clarinet-Bass, Clarinet-Treble, Saxophone-Tenor, Saxophone-Soprano, Saxophone-Baritone, Trumpet, Guitar, Glockenspiel, Piano, Church Organ, and Flute). The use of natural stimuli makes it more relevant and applicable to real-world listening situations, and the program also allows participants to individualize the training to suit their musical preferences and needs.

This thesis will detail the development of the program as well as the results from its application with CI recipients and hearing aid users. The structure of the thesis is as follows: Chapter two provides a review of the literature relevant to this study to highlight the importance of the present investigation and justify the methods used in developing and testing the proposed computerized pitch-perception program. Chapter three describes the methods used in developing the computerized pitch-perception training program, including the recording, editing, and analyzing of the musical instrumental sounds as well as male and female sung vowels. Two versions of the same training program were developed, V1T and V2T. The V1T program used interactive activities progressing from simple to complex tasks based on a predetermined progression sequence and V2T used an adaptive scheme in accordance with the trainee’s performance. Details of the training manual that accompanied the training program are also explained in Chapter three. Chapter three also details the results of a musical background questionnaire that was administered to each participant as well as the development of the pre-training and post-training test battery. The results obtained from the questionnaire and the pre-training and post-training test battery are presented in Chapter four. Finally, a discussion of the pertinent findings arising from the analyses is presented in Chapter five, with each of the hypotheses developed for the study discussed in detail. Chapter five also addresses the limitations of this study and directions for future research.

CHAPTER 2: LITERATURE REVIEW

This chapter is organized into four sections. The first section provides an overview of pitch perception in relation to speech and music perception and the development of pitch perception in normal hearing (NH) individuals and CI recipients. Sections two and three focus on the literature regarding the impact of pitch perception deficits on speech and music perception for CI recipients and hearing aid users. The fourth section provides preliminary evidence from a variety of studies showing a positive effect of auditory training on speech and music perception. At the end of the literature review, the rationale, research question, and hypotheses of this study are presented.

2.1 Pitch Perception

This study investigates the effect of pitch perception training on the pitch-related speech and music perception skills of the hearing impaired. Pitch is an auditory perceptual property that is related to the ordering of sounds mainly on a frequency scale, and also depends on the sound pressure and the waveform shape of the stimulus (ANSI, 1994). Pitch can be defined with reference to speech and music. Some aspects of the development of pitch perception in NH individuals and the hearing impaired have been investigated in the literature.

2.1.1 Pitch Perception in Speech

With reference to speech, pitch refers to the relative highness or lowness of the tone reflecting the rate at which the vocal folds vibrate ('t Hart, Collier & Cohen, 1990). In speech, pitch is important for the perception of vowels and voiced consonants. The pitch contour of the spoken utterances carries mainly the prosodic information in non-tonal languages and the lexical and semantic information in tonal languages (Houtsma, 1997). In

English, pitch changes are used linguistically only in a limited way, such as contributing to the stress pattern involved in differentiating the types of word (e.g., noun versus verb). Pitch cues primarily have a non-linguistic or para-linguistic function, such as determining the identity of a speaker (e.g., gender and age) and differentiating between sentence and statement or among different emotional states (e.g., angry, happy, or sad) (Luo et al., 2007; Peters, 2006). Intonation patterns help to differentiate between a question and a statement. Across different languages, questions normally consist of a rising pitch, whereas statements consist of a falling pitch glide (Pickett, 1999). Understanding emotions is also vital for effective communication as well as social interactions (Pereira, 1996; Scherer, 1984). The ability to interpret emotions accurately develops when an infant is exposed to spoken utterances (Walker-Andrews & Lennon, 1991). Infants can correctly discriminate between happy and sad vocal expressions when presented with facial expressions by the age of 5 months (Walker-Andrews & Lennon, 1991).

2.1.2 Pitch Perception in Music

Pitch, when defined with reference to music, is “that attribute of auditory sensation in terms of which sounds may be ordered on a musical scale” (ASA, 1960). In music, pitch is important to perceive the chords and melodies produced by most of the musical instruments (Yost, 2007). Music perception involves the perception of pitch, rhythm, loudness, and timbre (Gfeller et al., 1997). Accurate transmission of the pitch and timbre characteristics of a musical note is crucial for music perception (Gfeller et al., 2003). Pitch perception in musical context can be measured using the following tasks: (1) melodic pattern perception, (2) pitch discrimination, (3) pitch ranking, and (4) familiar melody identification tasks. Timbre is defined as “that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar” (ASA, 1960). Timbre perception can be measured through instrument identification tasks. Instruments are identified through the onset, steady state, and off-set cues (Howard & Angus, 2009). Both onset and steady-state cues are important for timbre recognition (Grasmeder & Lutman, 2006). Example showing that the onset of a musical sound may give cues for instrument recognition include: initial bow scraping in string instruments, flapping of the reed in reed instruments, hammering of piano, breathy noise at the beginning of a note and consonant onset with brass instruments (Grasmeder & Lutman, 2006). Harmonics or partials are present during the steady state. The presence and the number of harmonics play an important role in the identification of a pitched instrument. For un-pitched instruments, the distribution of energy across frequencies provides cues for the identification of the instrument (Grasmeder & Lutman, 2006). The frequency spectrum of all instruments depends on both individual factors (e.g., loudness, player, environment, and the manner in which the instrument is played) and the instrument factors (Grasmeder & Lutman, 2006). The main characteristics of an instrument are considered to be related to the frequency spectrum and the amplitude envelope varying over time as well as the spatial configuration of the sound source (McDermott, 2004).

2.1.3 Difference between the Speech and Music Spectra

There are many differences between the speech and music spectra. Speech is a well controlled spectrum with predictable perceptual characteristics whereas music spectra are highly variable and can vary based on the type and the genre of music, instruments, the way the instruments are being played, and the perceptual requirements of the listener (Chasin & Russo, 2004). Another difference is the differing crest factors between speech and music. The crest factor is the difference between the highest spectral peaks in a time-varying spectrum and the average or root mean square (RMS) value of a signal in decibels (Chasin & Russo, 2004). The crest factor is about 12 dB for speech and about 18 to 20 dB for music. In addition, the intensity levels have also been reported to be different between speech and music. A normal conversation ranges between 53 and 77dB and the shouted speech can attain a level of 83 dBSPL. Very soft music sounds can range between 20 and 30 dBSPL while loud sounds can exceed 120 dBSPL (Chasin, 2007). The frequency region for speech is between 500 Hz and 4000 Hz, with low frequencies generally providing phonetic and high frequencies providing phonemic information (Chasin & Russo, 2004). In contrast, music has a larger frequency range, with low fundamental frequency (F0) piano tones falling below 20 Hz and the upper partials of violin tones exceeding 20,000 Hz (Chasin & Russo, 2004). In addition to the spectral difference between music and speech, the inability to rely on visual cues for accurate music perception also sets music perception apart from speech perception. In speech perception, articulatory information is often readily visible (speech reading). In addition, a person can rely on context, body language, gestures, the use of conversation repair strategies, or closed caption or texts to infer the meaning of a conversation. In contrast, music changes in melody and harmony are most unlikely to be visible even when watching a singer or a musician in performance (Gfeller et al., 2000a). Because of these differences between speech and music spectra, an accurate music perception could be challenging even for NH listeners. Hence, the hearing impaired would require training to help perceive the degraded acoustic signals especially with regards to music perception.

2.1.4 Pitch Perception in Acoustic Hearing

Sounds can be either pure tones consisting of a single frequency or complex tones consisting of multiple discrete frequencies (Houtsma, 1997). Voiced speech sounds and musical instrument sounds are examples of complex tones (Oxenham, 2008). The salience of the perceived pitch of these complex tones relies on the degree to which the partial frequencies are harmonic, that is, the extent to which the frequency of one constituent tone is an integer multiple of that of another (Houtsma, 1997). For harmonic sounds, the pitch perceived depends on the F0, irrespective of whether the F0 is present, and/or is the most prominent frequency of the sound (McDermott & Oxenham, 2008). Sounds with a similar F0 are generally perceived to have a similar pitch regardless of the similarity of the spectra (McDermott & Oxenham, 2008).

The mechanism through which a complex tone is perceived involves coding both time and frequency domain information in the peripheral auditory system (McDermott & Oxenham, 2008). The pitch of a complex tone is derived either through the place of the highest excitation of the basilar membrane or through the phase locking of the interspike intervals of the neurons with characteristic frequencies close to the individual frequencies of the lower harmonics (Moore, 2007). A normally functioning cochlea has an infinite number of non-linear auditory filters with continuous characteristic frequencies (Moore, 2007). A complex tone is broken into its frequency components and matched to a corresponding place in the cochlea. This 'tonotopic map' will be maintained from the peripheral auditory system to the primary auditory cortex of the central auditory system (Kaas et al., 1999). The pitch of a complex signal can also be extracted from higher unresolved harmonics as higher harmonics elicit excitation patterns along the basilar membrane with a repetition rate equal to the F0 of the complex signal. The waveforms with the biggest peaks evoke neurons that are close to the characteristics frequencies of the higher harmonics. Auditory nerve impulses are separated by the time corresponding to the period of the sound. However, some theorists have emphasized that the pitch of a complex tone can be derived from both resolved higher harmonics and from resolved lower harmonics (Moore, 1989; Meddis & Hewitt, 1991). These theories also propose that perception of the pitch of a complex tone can also be affected by the relative phases of the higher harmonics (Houtsma & Smurzynski, 1990; Moore & Peters, 1992).

2.1.5 Development of Pitch Perception

In music, when we listen to a melody, an absolute pitch of each note played and a relative pitch (i.e., how pitches of successive notes relate to each other) are perceived (McDermott & Oxenham, 2008). Changes in the relative pitch, that is, whether a note is higher or lower compared to the previous note, is important for familiar melody recognition as well as for intonation perception (McDermott & Oxenham, 2008). The ability to perceive relative pitch appears to be present in infancy and continues to develop throughout the childhood years. Pitch perception skills in NH children develop early in childhood. For example, infants display the fundamentals of pitch processing skills, such as being able to distinguish between a pair of tones approximately an octave apart (Ward, 1954). By the second year of age, children are able to identify certain melodies as stable entities in their environment (Dowling, 1999). As children develop into adulthood, their melody processing skills develop under the influence of culture (Dowling, 1999) as well as individual experiences such as musical training and exposure levels (Deutsche et al., 1999). The ability to accurately identify pitch contour and interval size plays an important role in melody perception (Dowling & Bartlett, 1981). An infant can detect changes in the direction of pitch contour (Trehub et al., 1984). The difficulty exhibited by the 5-6 year olds in performing a pitch ranking task is reported to be related to their inability to understand the meaning of 'higher' and lower' in relation to pitch (Andrews & Madeira, 1977). Pitch ranking ability develops in infancy and reaches a maturity level that is similar to that of adults around the age of eight (Stalinski et al., 2008). These observations suggest that the fundamental pitch perception skill for NH individuals is an innate capacity that can be further developed through experience, training, and exposure, particularly during childhood.

2.1.6 Children with CIs

Prelingually deafened children are those who have no or little hearing at the time of birth or before their basic speech and language skills have developed (normally the age of four). Unlike postlingually deafened adults who have the advantage of using their memory for musical sounds to interpret musical stimuli, prelingually deafened children have limited, if any, prior exposure to music heard through a NH mechanism. Therefore, they do not have a memory of the neurological representation associated with a tonotopic pitch relationship to rely on for interpreting acoustic signals (Olszewski, 2006). However, since an enhanced development of the central auditory system with aural rehabilitation has been shown in the speech perception of early implanted children (Sharma et al, 2005), favorable implications for music development may be expected (Harrison et al., 2005). The greater neural plasticity associated with childhood (Ponton et al., 1999) is an advantage that may be useful for developing the pitch perception skills of pediatric CI recipients. To date, however, few studies have been conducted to evaluate the treatment efficacy of a training program for teaching musical skills to children (McDermott, 2004).

2.1.7 Impact of Cochlear Hearing Loss on Pitch Perception

Damage to the cochlear structures (i.e., inner and outer hair cells and spiral ganglion cells) can result in cochlear hearing loss. This affects the perception of pitch, timbre, and loudness. In relation to loudness, recruitment (i.e., a phenomenon where the rate of loudness growth with increasing intensity level is steeper than normal) is commonly observed in people with cochlear hearing loss. This reduces the listener's dynamic range, increases the perceived loudness fluctuation of the input signals, and exaggerates the perceived loudness of sounds whose amplitudes fluctuates over time, such as in the perception of speech and music (Moore, 1996; Moore, 2007). In addition, reduced loudness summation (i.e., summation of specific loudness at different critical bandwidths) for complex signals is observed in people with cochlear hearing loss. Consequently, a person with a cochlear hearing loss would perceive the relative loudness of complex signals differently compared to a NH listener (Moore, 2007).

In relation to pitch perception, damage to cochlear hair cells results in (1) reduced frequency selectivity, (2) broadening of cochlear filters (Arehart, 1994; Moore, 2007), and (3) diminished precision of phase locking (Woolf et al., 1981). The time taken for the travelling wave to propogate along the basilar membrane is also adversely affected due to the loss of active cochlear mechanisms and/or structures (Ruggero, 1994) resulting in dead cochlear regions, where inner hair cells and/or neurons are dysfunctional (Moore & Carlyon, 2005). The physiological consequence of cochlear damage on pitch perception is evidenced by poor frequency discrimination ability for both pure tones and complex tones and the inconsistemcies in performing pitch scaling tasks (Moore, 1996; Moore & Carlyon, 2005; Moore & Peters, 1992; Moore, 2007). In addition, diplacusis (i.e., perception of two different pitches between ears in response to a fixed frequency tone) is also seen in some individuals with cochlear hearing loss (Moore, 2007). Moore and Moore (2003a) suggested that the pitch perception of complex signals depends on both spectral and temporal analysis of a signal. Therefore, the perception of the pitch of complex tones can be affected by the impaired temporal resolution and intergration abilities resulting from cochlear hearing loss (Arehart, 1994; Moore, 2007; Florentine & Buus, 1988; Moore & Skrodzka, 2002). Due to the impaired ability to resolve low order harmonics of complex signals (Berstein & Oxenham, 2003; Berstein & Oxenham, 2006), reduced ability to use temporal fine structure cues of complex signals (Moore & Moore, 2003a), and poor frequency selectivity (Moore, 2007), people with a cochlear hearing loss may need to rely on the temporal envelope cues to obtain pitch information (Moore &

Moore, 2003a). However, pitch perception based on the temoral envelope cues has been found to be less effective than spectrally based cues (Kaernbach & Bering, 2001).

2.1.8 Pitch Perception in Electric Hearing

In electric hearing, the perception of the pitch of a complex acoustic signal is constrained by the limitations of CIs in simulating the temporal or place pitch mechanisms of a normal auditory system. With CIs, the temporal pitch information is obtained by varying the amplitude and/or rate of the stimulating biphasic pulse train (McKay, McDermott, & Clark, 1994, 1995). When the input signal is processed through most of the current speech processing strategies the temporal envelope cues are preserved, with the fine structure information of the input signal being discarded (Kong et al., 2005). Fine-structure temporal information has been shown to be important for pitch perception (Smith et al., 2002). In addition, most current commercially available speech processing strategies do not change the stimulation rate of the bi-phasic pulse trains as a function of the frequency of the input signal. When the rate of the stimuli presented to one cochlear site is increased from 50 to 300 Hz, an increase in pitch is observed (Moore & Carlyon, 2005). However, the upper limit relies on the position of the electrodes in the cochlea (Moore & Carlyon, 2005). Hence, CI recipients are usually unable to obtain pitch cues of sounds with a F0 beyond 261.63 Hz (Middle C of the western music scale) (McKay, McDermott, & Clark, 1994, 1995).

Place-based pitch information is obtained by electrically stimulating different cochlear locations with constant-rate pulse trains. As opposed to the normal hearing cochlea, the CI speech processors have a limited number of filterbanks comprised of wide band pass filters with a fixed-level centre frequency. In multi-channel devices, a single site of stimulation is activated by using a single intracochlear electrode in mono-polar stimulation or by using two closely spaced intracochlear electrodes as in the bipolar mode (McDermott, 2004). To resolve the individual harmonics of a complex signal, harmonics need to fall into different filter banks. Due to the wide filter banks used in speech processors, harmonics of the complex signals do not get fully resolved. Even if the harmonics are resolved, the CI recipient would only be able to determine which filters the harmonics fall into as they activate the corresponding electrodes instead of the exact frequency of the harmonics. This makes it difficult for CI recipients to determine the harmonic frequencies to accurately perceive the pitch of a complex sound. It has been observed that CI recipients rely more on the temporal pitch cues than on the place pitch cues to make reliable pitch judgments when listening to a complex signal (Laneau et al., 2006). The type of speech processing strategies used by different manufacturers plays an important role in determining the sound perceived by CI recipients. These speech processing strategies determine the sampling rate, rate of stimulation, electrodes to be activated, and the order, type of stimulation and the amplitude current (Looi, 2008b; McDermott, 2004; Loizou, 1998).

2.2 Pitch-Related Speech and Music Perception in Hearing Aid Users

This section details findings regarding the pitch perception skills of hearing aid users in speech and music perception.

2.2.1 Pitch-Related Speech Perception

Existing research investigating the emotion identification abilities of children and adults using hearing aids has reported a lower performance level in hearing aid users compared to their normal hearing peers (Rigo & Liberman, 1989; Shinall, 2005). Pereira (1996) compared the emotion identification abilities between 39 postlingually hearing impaired hearing aid users with mild to severe sensorineural hearing loss (SNHL) in one or both ears and 40 NH listeners. It was found that hearing aid users performed more poorly (M = 65%) in identifying emotions when intensity cues were intact than NH participants who scored 85% on the same task. Normalization of the intensity levels did not affect the performances. In addition, a negative correlation was found between the emotion identification scores and the severity of the hearing loss in hearing aid users (Pereira, 1996). In Pereira's (1996) study, sadness was the easiest emotion to understand and the cold anger emotion was the most difficult to recognize. When intensity cues were intact, it was shown in hearing aid users that the sad emotion was confused with the neutral emotion 24% of the time, cold anger with happiness at 30%, cold anger with neutrality at 21%, and hot anger with happiness at 12%. Similar findings were observed by House (1994), who studied the emotion identification ability of 29 hearing aid users with moderately severe to severe hearing loss. In that study, House (1994) concluded that hearing aid users have difficulty in identifying emotions and they often get happiness confused with anger, and sadness with neutrality.

Bordon et al. (1994) reported that individuals with SNHL have difficulty in perceiving F0 changes, hence, making the detection of intonation changes difficult (Bordon et al., 1994). However, those who have aided low frequency residual hearing at 500 Hz and below would be able to perceive the changes in intonation of sentences (Engen et al., 1983).

2.2.2 Pitch-Related Music Perception

Many studies have been carried out to assess the speech perception abilities of hearing aid users (Blamey et al., 2006; Chang et al., 2008; Ching et al., 1998; Gabrielsson et al.,1988; Jenstad & Souza, 2005; Moore, 2003b; Turner & Cummings, 1999; Vinay & Moore, 2007; Yund & Buckles, 1995); however, only a few studies have investigated the music perception of hearing aid users (Chasin & Russo, 2004; Franks, 1982; Leek et al., 2008; Looi et al., 2007; Looi et al., 2008a; Punch, 1978). Rudledge (2009) carried out a music listening questionnaire on 51 hearing aid users with mild hearing loss, 47 hearing aid users with moderate or worse hearing loss, and 19 hearing aid users assessed for CIs. Participants with mild hearing loss reported musical instrument sounds to be 'less noisy and less sharp' ($p < 0.001$) than participants with moderate hearing loss. Participants in both mild and moderate or worse hearing loss group preferred male singers over female singers (p = 0.021) and low-pitched instruments over high-pitched instruments (p = 0.04).

Past research suggests that both NH individuals and hearing aid users prefer a frequency response with more of the low frequency information when listening to music (Punch, 1978, Frank, 1982). Recently, Chasin and Russo (2004) found that the electro-acoustic characteristics, such as peak input limiting, number of channels, and compression level, may affect the music perception of hearing aid users. Chasin and Russo (2004) reported that single channel or multi-channel devices with a similar gain for each channel best for music perception in hearing aid users. In addition, music perceived with a peak input level of 115 or 105 dBSPL was reported to be more natural. Since the peak input levels were often limited for speech to a range between 80 to 90 dBSPL in conventional hearing aids, it appears that the optimization of music perception may require the use of a wider dynamic range of compression, with a threshold knee point of the compression being set at a level 5 to 8 dB higher than that for speech. A flat frequency response has also been suggested for use with the music listening program settings in hearing aids (Keidser et al., 1996).

2.3 Pitch-Related Speech and Music Perception in CI Recipients

This section describes findings regarding the pitch perception skills of CI recipients in speech and music perception and factors that may affect pitch perception in CI recipients.

2.3.1 Pitch-Related Speech Perception

Cochlear implantees have been found to show better performances in the perception of segmental speech information than for music perception (Dawson et al., 1992; Most, Rothem, & Luntz, 2009; Osberger et al., 1991; Shpak et al., 2009). The perception of F0 plays an important role in identifying intonation in speech (Laver, 1994) as well emotions (Banse & Scherer, 1996; (Bachorowski & Owren, 2003). Due to the technical limitations of the current CI devices in transmitting the F0 information, tasks that require effective pitch perception may be difficult for CI recipients (McDermott, 2004). Existing research that compared the emotion identification abilities of postlingually deafened CI recipients and NH controls reported lower scores for CI recipients than NH controls (Luo et al., 2007; Pereira, 2000a; Peters, 2006). In addition, when the intensity cues were normalized, scores of the CI recipients were found to deteriorate, suggesting a dependency on intensity cues for emotion identification. No such decrease was observed in NH controls (Luo et al., 2007; Pereira, 2000a; Peters, 2006). Past research also reports that postlingually deafened adult CI recipients perform more poorly than hearing aid users in identifying emotions (Luo et al., 2007; Pereira, 2000a; Peters, 2006).

Most and Aviner (2009) compared the emotion identification abilities of prelingually deafened adolescents using CIs with those of NH individuals and hearing aid users in auditory, visual, and both auditory and visual modes. Superior performances in the auditory mode were observed for the NH individuals compared to the hearing impaired while no significant performance difference was observed between the two hearing impaired groups in any of the modes. Shinall (2006) also reported that children with CIs performed significantly poorer than NH peers in the identification and discrimination of emotions.

Most and Paled (2007) reported that children using CIs performed significantly poorer than children with either severe or profound SNHL using hearing aids in identifying questions/statements. However, it was observed that substitution of a statement for a question was significantly higher (75.81%) than substitution of a question for a statement (24.19%) among both groups of participants (Most & Paleed, 2007). Peng et al. (2008) also reported that prelingually deafened children using CIs had difficulty in identifying rising intonation, with only a 70% rate of correctly differentiating between questions and statements. Holt and Fletcher (2010) examined the perception of intonational rises in 19 NH and 11 CI adolescents. Results revealed that the CI group could only discriminate F0 peak alignments above chance level when the F0 peaks of the nuclear pitch accent (i.e., the F0 change that marks the beginning of an intonational constituent) of the utterances were 160 ms apart (Holt & Fletcher, 2010). In contrast, the NH group could discriminate F0 peaks above chance level even when the peaks were only 40 ms apart. In summary, these findings indicated that both postlingually deafened adults and prelingually deafened children using CIs performed more poorly than both hearing aid users and NH listeners in pitch-related speech perception tasks. These findings also highlight the need for habilitation/rehabilitation options to help improve the pitch-related speech perception skills of both adult and pediatric CI recipients.

2.3.2 Pitch-Related Music Perception

Findings from studies employing survey questionnaires (Gfeller et al., 2000b; Leal et al., 2003) indicate that postlingually deafened CI recipients are often disappointed or frustrated with the way music sounds via the implant. Looi and She (2010) found a significant decrease in enjoyment of music for postlingually deafened adult CI recipients with their CIs compared to before hearing loss. Results also revealed that CI recipients preferred listening to individual instruments over instrumental families, small-group performances over large number of performers, instruments in the low frequency range, and country and western music styles.

It has been found that CI recipients perform less accurately than NH individuals in melodic pattern recognition tasks (Dorman et al., 1991; Gfeller et al., 1997). Galvin et al. (2007) investigated the identification of nine melodic contours using 3-tone complexes, with the interval between successive tones varying between 1 and 5 semitones. Better performance was observed for a large interval size, with a wide range of variability in percent-correct scores ranging between 14% and 91% (Galvin et al., 2007). Findings of a large variability of performance scores in CI recipients appear to be common in the literature, suggesting that the training effect on the performance of this group may also be variable.

Studies assessing music perception in CI recipients show that they score lower in pitch perception tests than in tests related to perceiving temporal information such as rhythm (Gfeller et al., 2002a; Kong et al., 2004a; Leal et al., 2003; McDermott, 2004). Both children and adults with CIs have also been shown to perform more poorly in recognizing familiar melodies presented without the rhythm cues when compared to those with normal hearing (Gfeller & Lansing, 1991, 1992; Gfeller et al., 1997; Kong et al., 2004a; Olszewski, 2006). Looi et al. (2008c) reported that adult hearing aid users performed significantly better than CI recipients in familiar melody identification tasks when rhythm cues were intact. Existing research reports that children with CIs score lower than normal hearing children on tests involving recognizing songs from melody-alone conditions (Nakata et al., 2006; von Paisal et al., 2006; Mitani et al., 2007). Mitani et al. (2007) examined the ability of prelingually deafened children with CIs in identifying familiar melodies through incidental exposure. Seventeen prelingually deafened pediatric CI recipients were tested by using three versions of the main melody (original, instrumental and synthesized flute) of 14 theme songs of popular TV dramas. Results revealed that these pediatric CI recipients performed above chance level in identifying the original version of the songs; however, performance remained at chance level for identifying both instrumental and flute versions of the main melody.

Pitch discrimination involves identifying two tones as same or different in pitch (Gfeller et al., 1997). Studies have shown that CI recipients performed significantly more poorly than NH counterparts in the pitch discrimination tasks (Fujita & Ito, 1999; Gfeller et al., 1997; Looi et al., 2008c). For example, Gfeller et al. (1997) reported that NH individuals required two notes to have a mean difference of 1.13 semitones (range: 1 to 12 semitones) and CI recipients that of 7.56 semitones (range: 1 to 24 semitones) to be able to correctly perceive them to be different. Sucher and McDermott (2007) compared the pitch ranking abilities of 8 CI and 10 NH adults and found that CI recipients performed significantly more poorly than NH participants in pitch ranking notes between 1 to 6 semitones apart.

The perceptual skills of CI recipients in performing pitch-related music perception tasks have also been studied. Gfeller et al.'s (1998 and 2002c) studies investigated the musical instrument recognition and appraisal abilities of CI and NH participants. In both of these studies, NH participants performed significantly better than the CI recipients in the musical instrument identification task and had better appraisal scores. Looi et al. (2008c) investigated the music perception of 15 CI and 15 hearing aid users with similar levels of hearing loss. Participants were assessed on rhythm discrimination, pitch ranking, instrument recognition, and melody identification tasks. Results revealed that hearing aid users performed significantly better ($p < 0.001$) than CI recipients in the pitch ranking of sung vowels at 3, 6, and 12 semitones apart and also on the familiar melody identification task. The CI group's performance was not significantly better than the chance level performance in discriminating between sung vowels that were three semitones apart (51.75% correct, $p = 0.238$). However, the CI and hearing aid groups did not significantly differ in performing the rhythm and instrument recognition tasks. Even though hearing aid users performed better than CI recipients in the pitch perception task, both groups were unable to achieve the same levels as NH adults (Looi et al., 2008c). Furthermore, in Looi et al.'s (2008c) study, instrument identification was studied under three categories: single musical instruments, solo instruments with background accompaniment, and musical ensembles. There was no statistically significant difference between the CI recipients and hearing aid users for any of the tasks; however, the instrument recognition ability for both subject groups decreased as stimuli complexity increased.

Although children with CIs seem to be more involved in musical activities than adult CI recipients, they still exhibit difficulties in certain aspects of music perception when compared to normal hearing children. Looi and Radford (2011) reported that children using CIs performed poorer than their NH peers in the pitch ranking task. The children using CI obtained 67.45%, 77.6%, and 83.3% correct in comparison to 88.79%, 94.58%, and 96.94% scores obtained by the NH participants on the 3, 6, and 12 semitone interval levels respectively. These findings indicate that pitch perception remains a challenge to both adults and children who use CIs.

2.3.3 Factors that Affect Pitch Perception in CI Recipients

The frequency resolution of a CI is dependent on the placement of the electrodes, the speech processor and the speech processing strategy used.(Lan et al., 2004). Since current CI devices only utilize up to 22 electrodes to represent approximately 20,000 hair cells in a normal hearing cochlea, a broad range of frequencies are distributed over a small number of electrodes. Consequently, there is often a mismatch between the designated pitch of the neurons at a given location and the frequencies assigned to the electrodes activated for stimulation, as well as less precise frequency resolution (Fujita & Ito, 1999; Kong et al., 2004a). Such a mismatch may also arise from having the electrode array inserted only to one and half turns of cochlea (Skinner et al., 2002). As for temporal information, while the pitch information received by a normal hearing individual can be coded on the basis of the pattern and firing rate of nerve impulses in response to the incoming acoustic vibrations over time, current speech processing strategies in CI devices stimulate electrodes at a fixed pulse rate which means that the temporal pitch cues would only be available through modulations in the amplitude of the pulse trains.

In addition to the technical limitation of the CI devices in coding pitch information, other factors affecting the pitch perception of CI recipients may include (i) device-related factors such as full or partial insertion of the electrode array (Kirk et al., 1997), the number of active CI electrodes (Friesen et al., 2001), the number of spectral channels (Friesen et al., 2001), stimulation rate (Battmer et al., 2010; Vandali et al., 2000), and the speech processing strategy used (Battmer et al., 2010; Sehgal et al., 1998), as well as (ii) subject-related factors such as the number and pattern of the surviving auditory neurons, the location of these neurons relative to the target electrodes (McDermott, 2004), impedance of the tissues surrounding the electrode array (Busby et al., 1994), duration of the deafness (Gfeller et al., 2002a), and cognitive factors (Pisoni, 2000). In summary, existing research shows that the technical limitations of the CIs in conjunction with individual subject factors may lead to difficulties in encoding and decoding pitch information, which can impact on speech and music perception.

2.4 Auditory Training

Auditory training has been shown to facilitate the improvement of an individual's ability to detect and discriminate acoustic cues that are vital for speech perception (Tremblay, 2007).

Gfeller et al. (1999) and Kistler (2011) reported that learning characteristics need to be considered while designing a training program for adults. Adults prefer to be aware of the reasons for learning a particular material and also consider the advantages and disadvantages of undertaking a task before attempting it (Kistler, 2011). Adults learn materials that are meaningful and have immediate utility (Gfeller at al., 1999). Adults prefer instructions that can be easily followed, that match with their time constraints, that are already available (Gfeller et al., 1999), and that are self-directed (Kistler, 2011). Adults prefer to engage in tasks that help improve their quality of life or solve their problems. They also respond to tasks that are more internally motivating, such as improving self-esteem and quality of life (Kistler, 2011). In addition, factors related to physical, cognitive processes related to aging need to be considered when designing a training program (Gfeller at al., 1999).

According to the existing literature, most of the auditory training programs have used either an adaptive training protocol or a fixed protocol using identical stimuli to deliver the training stimuli to the participants (Amitay et al., 2006b; Roth et al., 2006; Roth et al., 2008). Roth et al (2006) carried out a study in which the effects of training using fixed-level protocol with identical stimuli on frequency discrimination thresholds were investigated. Results revealed an improvement in the performance of the training group that was trained to select the tone of the higher pitch in a pitch discrimination task using identical tone pairs. The results suggested that perceptual learning can occur even when the perceived stimuli seem to be similar in perceptual dimensions (Roth et al., 2006). Roth et al. (2008) compared the effects of types of training using adaptive and fixed type protocols on a difference limen for frequency threshold. Twelve adult participants were randomly assigned to “adaptive and fixed” training groups. The participants in the “fixed” group were trained by using 1kHz identical tone pairs and the participants in the “adaptive” group were trained using tone pairs that varied in a 2-down 1-up adaptive procedure. Results revealed that the amount of improvement was not dependant on the type of the training protocol used (either adaptive or fixed). The effects of generalization were tested in an untrained frequency (2kHz) and also on an untrained ear. Results revealed that the effects of learning generalized to the untrained ear in both training groups , however, when the generalization of learning to the untrained frequency was measured, more improvement was observed for the participants trained with “adaptive” protocols than those were trained with the ‘fixed” training (Roth et al., 2008).

2.4.1 Hearing Aid Users

Olsen (2010) evaluated the effectiveness of the ‘listening and communication enhancement’ (LACE) program on 26 adult hearing aid users. Participants were divided into three categories: new hearing aid users with training, experienced hearing aid users with training, and new hearing aid users without training. The training group completed twenty 30-minute training lessons using the LACE take-home DVD program over a period of 4 weeks. The training group was evaluated at baseline, after 2-weeks of training, and after 4 weeks of training. The control group was evaluated at baseline and after 4 weeks of hearing aid use. Results revealed that the performance of both new and experienced hearing aid users in speech-in-noise tests improved after training. Additionally, the new hearing aid users were also found to show a statistically significant improvement following training compared to experienced users.

2.4.2 CI Recipients

As CIs provide different auditory information to normal acoustic hearing, cortical areas may undergo changes in response to electrical stimulation to facilitate the perception of modified acoustic signals (Naito et al., 2000). This is evident from the PET (Positron Emission Tomography) studies comparing the activities of the cortical areas of CI recipients with those of NH controls while listening to speech (Limb et al., 2010; Naito et al., 2000). The extent of adaptation to the incoming signals received via a CI depends on the severity of the spectral mismatch of the CI recipients (Fu & Galvin, 2007). However, passive adaptation itself may not be adequate to facilitate the perception of spectrotemporal cues required for the perception of complex acoustic signals such as speech-in-noise or music. Active auditory learning may enable better adaptation to sounds perceived through the CI (Fu & Galvin, 2007a).

Existing research suggests that some amount of improvement in speech perception can be obtained through auditory training in postlingually deafened CI recipients (Fu & Galvin, 2007b). For example, Fu et al. (2004a) prescribed a word-based computerized training program to ten adult CI recipients. The training taking place at home for one hour per day and five days per week for four continuous weeks. Results suggested an improvement in vowel recognition [$t(10) = 8.83$, $p < 0.001$], consonant recognition [$t(7) = 4.09$, $p < 0.01$], and hearing-in-noise test (HINT) sentence recognition [$t(2) = 14.59$, $p < 0.01$] scores following training. Stacey at al. (2010) carried out an intensive 15-hour word and sentence training computerized training program with postlingually deafened adult CI recipients. Results revealed a significant post-training improvement of 8% in consonant discrimination but no significant improvement in vowel discrimination or sentence perception tasks.

The effect of auditory training on the music perception of the CI recipients has also been investigated. Gfeller et al. (1999) developed a take-home computer-based music training program for the CI recipients. A variety of tasks such as pitch, timbre, and melody perception tasks were included in the training program. In addition, real-life musical excerpts from different musical styles and self-directed exploratory tasks were incorporated into the program. Participants completed the four, 30 minute sessions over a period of 12 weeks. This program was evaluated over several studies. Gfeller et al. (2000a) evaluated the effect of training on melody recognition and appraisal by adult CI recipients. No statistically significant improvement was observed in the training group for the simple melody recognition task. However, the training group showed a significant pre- to post-training improvement in the scores for the complex song recognition ($p < 0.0001$) and appraisal ($p < 0.0001$) conditions. It was, therefore, posited that the training might have helped the training group to develop compensatory strategies to help identify familiar melodies (Gfeller et al., 2000a).

Gfeller et al. (2002b) carried out a timbre training program on adult CI recipients. Twenty four adult CI recipients were randomly assigned to either training or a control group. Participants completed a 12-week timbre training program consisting of musical excerpts of musical instruments covering three frequency ranges and four instrumental families. The training group showed a significant post-training improvement ($p < 0.001$) in timbre recognition and appraisal ($p < 0.02$). Galvin et al. (2007) carried out an adaptive melodic contour training program on six postlingually deafened adult CI recipients. Five-note, nine melodic contour patterns was used in the training program. The distance between two successive notes varied from 1 to 5 semitones. The duration of each note in the five-note contour was 250 msec and the interval between two successive notes was 50 msec. The training stimuli were delivered via a laptop computer. Five participants trained at home 30-

minutes per day, five days a week for a period of 1 to 8 weeks. The remaining participant trained at the lab for 3 hours per day for five days. The average pre-to post-training improvement for the melodic contour identification was 27%. Training was generalized to familiar melody identification task (without rhythm cues) with a mean improvement of 20.8% observed across participants.

The mechanisms through which pediatric CI recipients perceive sounds are different from those of the postlingually deafened adult CI recipients or hearing aid users. Prelingually deafened pediatric CI recipients have a congenital SNHL or acquired a SNHL prior to developing speech and language skills. Damage to the peripheral auditory receptors is often accompanied by a loss of spiral ganglion cells, a reduction of the size of the neurons, and loss of the cochlea nuclei (Syka, 2002). As the auditory system matures postnatally (Sharma et al., 2005), sensory maps of the central auditory system undergo changes as a result of the peripheral sensory input during infancy (Syka, 2002). A lack of auditory information reaching the cortical areas due to the aforementioned changes could potentially affect the maturation of the auditory pathway. Cortical auditory evoked potential (CAEP) studies provide information regarding the maturation of the auditory pathway (Eggermont et al., 1997). In normal hearing children, the latency of the P1 component shown in the CAEP reaches an adult-like level by the age of 15 years. In implanted children, the time taken to reach the adult-like P1 latency is delayed by an amount equal to the duration of the deafness prior to the implantation (Eggermont et al., 1997). As evidenced by the CAEP studies, reorganization of the cortical pathways is observed in response to auditory stimulation in implanted children (Gilley et al., 2008). The extent to which the reorganization of the central auditory pathway occurs largely depends on the age at which the children are implanted (Gilley et al., 2008).

It has also been reported that prelingually deafened pediatric CI recipients benefit from auditory training programs (Abdi et al., 2001). Factors that have a potential to affect the training effect on the speech perception skills of children with CIs have also been identified, such as the age of implantation (Sharma et al., 2002; Tyler et al., 1997), the amount of daily use of CI (Fryauf-Bertschy et al., 1997), the number of years of CI use (Tyler et al., 1997), any medical condition that involves the central nervous system (Pyman et al., 2000), and the communication mode used before and after implantation (O'Donoghue et al., 2000).

Abdi et al. (2001) carried out a study in which the effects of using a music training program based on the Orff method was evaluated as a habilitation method for the children using CIs. The Orff method is an approach to teach music, based on a sequence of facilitating activities incorporating perceptual (e.g, learning to discriminate rhythms and pitches) and production tasks (e.g., learning to play a simple musical instrument) progressing from simple to more sophisticated levels. Twenty three children, aged between 2.5 to 12.5 years took part in this study. Results revealed an improvement in playing a musical instrument in all the participants. Similarly, Wu et al. (2007) carried out a take-home computer-based training program to evaluate the effect of training on prosody (mandarin tone recognition). A total of seven prelingually deafened pediatric CI recipients and three children using hearing aids were recruited. The participants had to train for half an hour per day, 5 days per week, for 10 successive weeks. Results suggested a significant improvement in consonant, vowel, and mandarin tone recognition performance. These findings suggest that music training may be beneficial to individuals with CIs in both speech and music perception.

2.4.3 Transfer and Generalization

Tremblay et al. (1997b) found that training can generalize to listening situations beyond training sessions. The transfer of learning refers to the ability of a listener to generalize the acquired improvement in the perception of the training stimuli to perceiving a novel stimulus with similar acoustic parameters outside of the training session. Past behavioral studies have shown that training facilitates the transfer of learning of one place of articulation (pre-voiced bilabial) to another (pre-voiced alveolar). Training has also been found to help improve the discrimination and identification of speech sounds with phonemically identical, spectrally different, and unfamiliar VOT (voice onset time) contrasts (Tremblay, 1997). In addition, these changes in perception were reflected in electrophysiological data, showing an increase in the area of MMN (mismatched negativity), which is the cortical potential elicited by an irregularity in otherwise regular repetition of acoustical stimuli (Limb et al., 2010) and a decrease in the onset of the mismatched responses. The underlying neurophysiological changes and the generalization abilities of the learning and the transfer of the learned stimuli have been found to be in both cortical and sub-cortical areas (Kraus et al., 1995).

2.5 Summary of the Literature Review

Accurate pitch perception is crucial for pitch-related music and speech perception tasks. Pitch is important for identifying para-linguistic features of speech such as emotions and questions versus statements. In music pitch helps identifying melodies, intervals, and musical instrumental sounds. As evidenced by past literature damage to cochlear structures affects the pitch perception of both pure tone and complex tones. Hearing impaired individuals benefit from using hearing aids and/or CIs. However, due to the technical limitations of these devices and the physiological consequences of hearing loss, accurate pitch perception remains a challenge to both CI recipients and hearing aid users. Both prelingually and postlingually deafened CI recipients and postlingually hearing impaired hearing aid users exhibit poor performance compared to their NH peers in pitch-related speech (e.g., emotion and question/statement identification) and music perception tasks (e.g., familiar melody identification and pitch ranking). Results obtained from neurophysiological studies and auditory training programs suggest that both CI recipients and hearing aid users are able to benefit from auditory training to some extent regardless of the technical limitation of the hearing aids and cochlear implants.

In summary, preliminary findings have shown that auditory training has a great potential for improving the speech and music perception of CI recipients and hearing aid users. The rationale for conducting a study to specifically investigate the effect of pitch perception training on the pitch-related speech and music perception skills of the hearing impaired as follows.

2.6 Rationale

During the past two decades, there has been a rapid growth in the industry of CIs and hearing aids due to the increased awareness of hearing loss and the advances in technology. Emphasis in past research has focused on improving speech perception through CIs and hearing aids (McDermott, 2004; Chasin, 2004). With growing demands for a better listening experience, research is now focused on improving the perception of other auditory stimuli to enhance the quality of life of CI recipients and hearing aid users. Factors that may contribute to quality of life include good speech perception in both quiet and noisy situations, perception of paralinguistic features of speech, such as the ability to differentiate between a question from a statement and between different emotions, and perception of music.

Hearing aids have been designed basically for speech perception, with an emphasis on preserving the spectral features of speech sounds. As the spectral characteristics of music are different from those of speech, the music-related spectral parameters are not taken into account when designing hearing aids (see section 2.1.3 for the differences between speech and music spectra). This leads to the poor music perception often seen in hearing aid users (Chasin & Russo, 2004; Ross, 2009). Although many hearing aid manufacturers use a special program for processing musical input for hearing aid users, a large number of hearing aid users still seem to be dissatisfied with the perception of music through their hearing aids (Rutledge, 2009). Research suggests that CI recipients demonstrate good speech perception in quiet (Fetterman & Domico, 2002) while their perception of complex acoustic signals such as music and speech perception in noise remains a challenge (Fetterman & Domico, 2002; Fu & Galvin, 2007b; Gfeller et al., 2007). The difficulty CI recipients experience in perceiving the more-complex acoustic stimuli is partly due to the limitations in pitch perception (Wei et al., 2004; Xu et al., 2004).

Studies of the pitch perception of NH infants suggest that infants, between 33-35 weeks of gestational age, respond to pure tones between 100 Hz and 3000 Hz (Hepper & Shahidullah, 1994). Infants can discriminate upward and downward contours at birth (Carral et al., 2005) and, at 2 months of age, can respond to a change in half octave piano tones (He et al., 2007). Prelingually deafened children are either born with, or later acquire a severe-to-profound SNHL before the age of language acquisition. In contrast to postlingually deafened CI recipients, who have previous experience in listening to sounds through acoustic hearing prior to receiving their CIs, prelingually deafened CI recipients have very limited, or no experience listening to sounds through acoustic hearing. They grow up listening to speech and music through their implant (electric hearing). Thus it is quite likely that prelingually deafened CI recipients would perform pitch-related tasks differently compared to postlingually deafened CI recipients.

As mentioned, poor pitch perception skills observed in CI recipients have been linked to limitations in current speech processing strategies such as extracting and encoding the F0 and harmonic structure information (Wei et al., 2004). Even with the limitations of current technology, evidence from perceptual and cognitive studies (Pizzo et al., 2000) and aural rehabilitation studies suggest that some aspects of speech perception (Fu et al., 2005a, 2005b; Fu et al., 2004a; Fu & Galvin , 2007b) and music listening (Abdi et al., 2001; Gfeller et al., 2002b; Gfeller et al., 2000a; Yucel et al., 2009) can be improved with auditory training.

In the Looi and She's (2010) study, 54% of the CI recipients indicated interest in taking part in a music training program. The CI participants ranked music listening skills in terms of their importance to music listening and enjoyment on a scale of 1 to 8, with 1 being most interested and 8 being least interested. The ability to recognize previously known tunes prior to implantation was considered the most important music listening skill required to help improve music listening and enjoyment. The ability to recognize commonly known tunes was ranked second and the ability to recognize commonly known musical instruments and the ability to hear pitch changes were ranked third. All of these tasks require the ability to perceive pitch accurately. These findings agree with the previous studies that CI recipients perform poorly in pitch perception tasks, hence, it is not surprising that CI recipients are interested in a training program that contains tasks to improve their pitch perception. Looi and She (2010) suggested that pitch training for CI recipients should incorporate wide pitch intervals and an adaptive procedure to account for individual variability. As CI recipients are more accurate in perceiving low-frequency information, starting tasks with low-pitched instruments or in lower-pitch ranges has been recommended by the researchers (Looi & She, 2010). In the same study, participants indicated preference for 30-minute training sessions two or three times a week (Looi & She, 2010). These observations were taken into consideration when designing the computer-based training program to be used in the present study.

2.7 Statement of the Problem

Accurate pitch perception is crucial for identifying paralinguistic functions of speech and also for music perception. With the increase in the number of adults and children using CIs and hearing aids, there is a growing need for a training program that encompasses both speech and music perception skills. Hence, a pitch training program that would help improve the pitch-related speech and music perception skills of both CI recipients and hearing aid users would be a valuable rehabilitation tool.

The impact of training on the pitch-related speech and music perception skills remains to be fully explored. There is evidence of the benefits of music training for postlingually deafened adults (Gfeller et al., 2002b; Gfeller et al., 1999; Gfeller et al., 2000a) as well as prelingually deafened children using CIs (Abdi et al., 2001; Blumberg et al., 2006). There is also a lack of research investigating music training for hearing aid users. As there have been very few studies comparing the training effect for trainees in different age or hearing impaired groups, this research developed a computerized pitch-perception training applicable to both children and adults and investigated the effect of pitch-perception training on the speech and music perception skills of postlingually deafened adults using cochlear implants (CIA), prelingually deafened children using cochlear implants (CIC), and postlingually hearing impaired hearing aid users (HA).

2.8 Hypotheses

The hypotheses developed for this study were:

1. **The NHA group will perform better than the HA and CIA groups and the NHC group will perform better than the CIC group in the baseline pre-training test measures of speech and music perception.**

   Hypothesis One was proposed based on the finding from the literature that the limitations in CIs and hearing aids and known physiological impact of the hearing loss on the auditory system of the CI and HA users may have an adverse impact on pitch perception, which plays an important role in speech and music perception.

2. **The HA group will perform better than both CIA group in the baseline pre-training test measures.**

   Hypothesis Two was proposed based on the findings from a literature review of studies concerning the impact of the limitations of the CI device on pitch perception as discussed in Section 2.3.

3. **The post-training test scores obtained by the V1T groups will be significantly higher than their pre-training test scores and the post-training scores of their control groups.**

4. **The post-training test scores obtained by the V2T groups will be significantly higher than their pre-training test scores.**

   Hypotheses three and four were proposed based on the preliminary findings showing a positive effect of auditory training on speech and music perception as described in Section 2.4. The difference between V1T and V2T will be described in Section 3.1.

5. **The overall post-training improvement will be higher for the V2T groups than the V1T groups.**

The difference between V1T and V2T was that the V1T program kept a trainee at a fixed interval level for a fixed amount of trials while the V2T program progressed to a more difficult level if the trainee achieved a satisfactory level or regressed to a less difficult level if the trainee did not achieve a preset criterion level within a set number of trials. Hypothesis Four was proposed based on the assumption that since the V2T program employed an adaptive approach, which was individualized and equivalent to the hierarchical approach commonly used in many auditory training programs, it might provide a greater challenge to the trainee and hence maximize training effectiveness.

CHAPTER 3: METHOD

This chapter details the general study design, participants, materials, and procedures employed in the development and testing of the training program. It is divided into five sections. The first section (Section 3.1) describes the general study design. The second section (Section 3.2) describes the participants who were involved in this study. The third section (Section 3.3) describes the test materials and the questionnaires that were developed. The fourth section (Section 3.4) details the procedures employed in testing the research participants. The last section (Section 3.5) describes the design of the two versions of the training program.

Ethical Approval

The ethical approvals for the study were obtained from both the Health and Disability Ethics Committee (NZ Ministry of Health) and the University of Canterbury Human Ethics Committee. All procedures undertaken were in accordance with these approvals. Participation in the present study was voluntary and participants were free to withdraw from the study without having to give any reasons. All participants were informed of the general purpose and the procedure of the study (see Appendix 2) and signed the consent forms before participation (see Appendix 3).

3.1 Study Design

This research involves (1) the development of a self-training computerized pitch-perception training program, and (2) a prospective study with a group design conducted to evaluate whether this program, when used as a self-training tool, would help improve the pitch-related speech and music perception skills of individuals using CIs or HAs. Two versions of the training program were developed, which will be referred to as V1T and V2T.

Details about the development of the program, participants, and testing protocols are described in later sections.

This study involved both normal hearing and hearing impaired individuals. The NH participants served as the controls and included NH adults (NHA) and NH children (NHC). These NH participants were tested before and after a ten-week waiting period (break). The NH control participants were tested for two main reasons: (1) to provide baseline pre-training results for comparing the hearing impaired groups to and (2) to evaluate whether the performance of the participants of the training group could reach that of the normal hearing participants after completing their pitch perception training. The three hearing impaired groups, namely, the HA, CIA, and CIC groups, were further subdivided into two halves and randomly assigned to a training or a control group. The hearing impaired control participants were used as a baseline for comparison to the hearing impaired participants who underwent training. All hearing impaired participants and the parents of the pediatric CI recipients completed a pre-training musical background questionnaire prior to the assignment of control and training groups. After a pre-test session, participants assigned to V1T underwent training for a ten-week period and were tested again at the end of the training. The hearing impaired control participants were tested before and after a ten-week waiting period. A flowchart displaying the steps involved in the study for the NHA and NHC groups and the hearing impaired participants involved in V1T is shown in Figure 1.

The V2T program was administered, after the V1T groups had completed the training, to the majority of the participants who served as controls for the V1T groups. As a means of pilot testing this program, the majority of the hearing impaired participants who served as the ‘control’ group for V1T were later recruited to participate in V2T. There was no control group for V2T. A flowchart displaying the steps involved in V2T is provided in Figure 2. At the completion of either V1T or V2T, each participant completed a post-training questionnaire that was designed to determine the participants' views regarding the efficacy of the training program.

This study was aimed at finding the effects of pitch-perception training on pitch-related aspects of speech and music skills of the hearing impaired individuals using their everyday personal sensory devices. This design was implemented to find out whether pitch-perception training could help hearing impaired participants to improve their pitch-related aspects of speech and music skills regardless of the brand, or the type of the hearing aid or the CI. Hence, the hearing aid participants were not categorized according to the type or the brand of the hearing aid device used and the CI recipients were also not categorized based on the brand of the CI device or whether they were CI-Only, bimodal or hybrid users.

Another important factor to consider is that this study was designed as a pilot test with the intention of making necessary changes to the pilot version of the computerized-pitch-perception-training program based on the results obtained from participants who completed the pilot-training program. At the initial stages of the design of this study, prior to the recruitment of the participants, the inclusion criteria were discussed with the clinicians and it was assumed that the researcher of this study would be able to recruit at least 20 participants for each category of CIA, CIC and HA users. However, only 16CIA, 20 HA and 6 CIC users could be recruited. Hence, 8CIA, 10HA and 3 CIC participants were assigned to the V1T group and 8 CIA, 7 HA and 2 CIC participants were assigned to the V2T group. It would have been ideal to have more CIC participants as the results obtained by 3 CIC participants in V1T and V2T cannot be generalized to a larger population. Hence, the results obtained from the CIC group were interpreted with caution and their results were considered more as case examples.

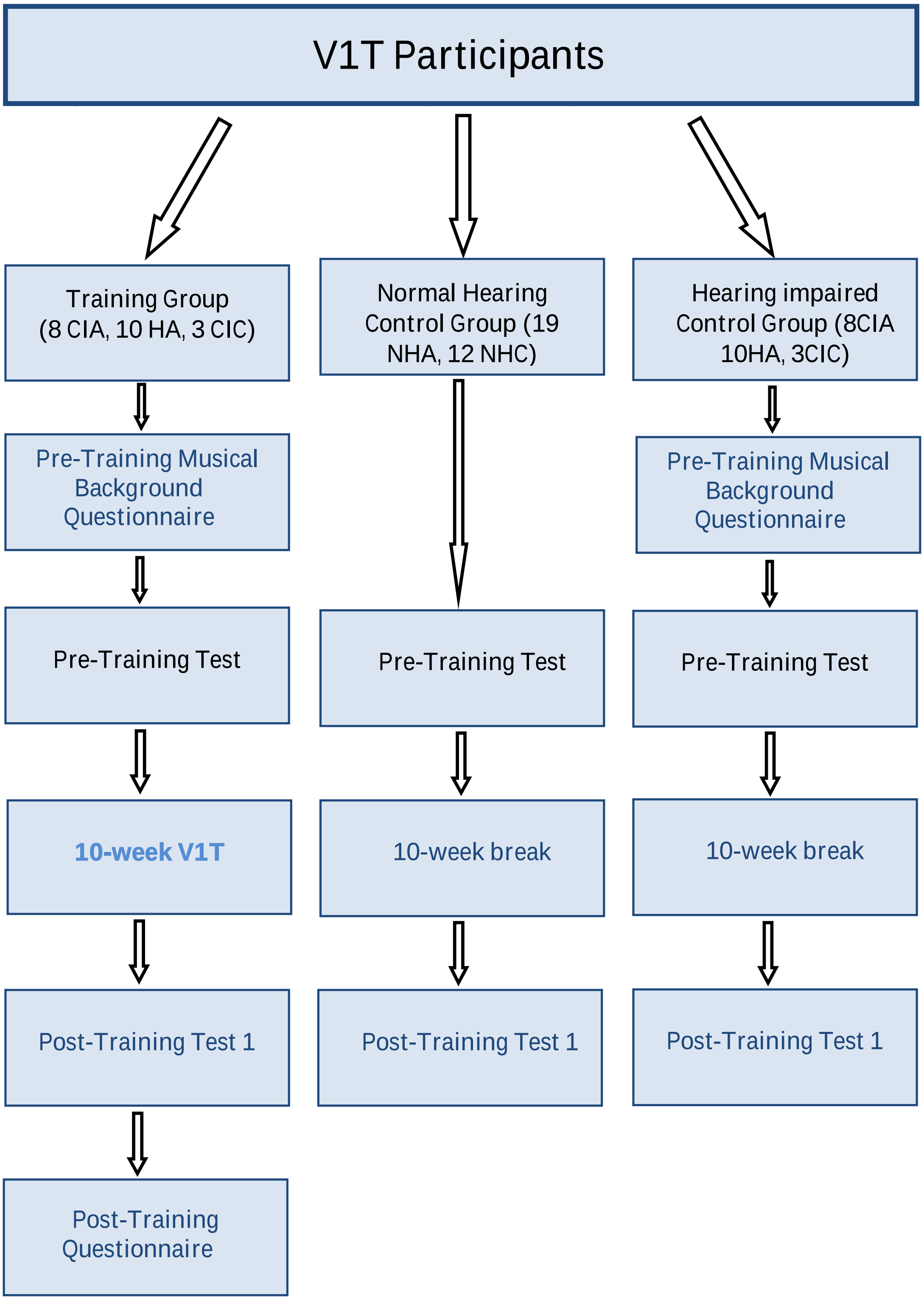

Figure 1. Flowchart of the steps involved in the Version 1 training (V1T) period of the study.

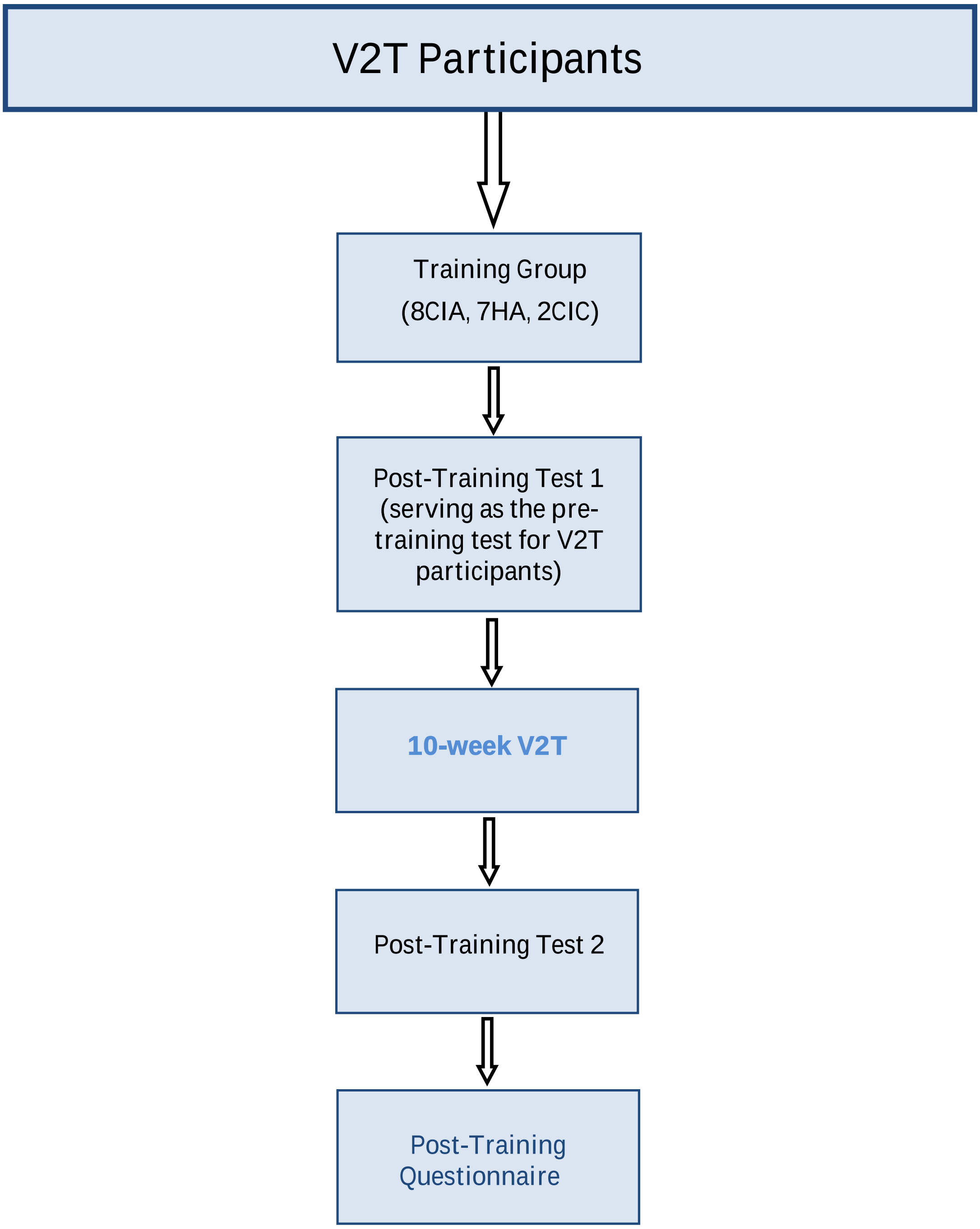

Figure 2. Flowchart of the steps involved in the study specific to the Version 2 training (V2T) period of the study.

3.2 Participants

A convenience sampling strategy was used to recruit individuals with normal hearing, as well as those with cochlear implants or hearing aids. The NHA participants were recruited from the University of Canterbury through an invitation letter advertised on the Student Association website. This letter was also emailed to University staff members. The NHC participants were recruited through invitation letters that were advertised in school newsletters. For the NHA group, the subject inclusion criteria were that they (1) be native speakers of NZ English or have been speaking NZ English for more than 10 years, (2) be above 18 years of age, (3) have normal hearing in both ears, and (4) have no cognitive, neurological or physical impairment that would impede their ability to understand test instructions. Similar inclusion criteria were used for the NHC group except the age range was stipulated between 12 to 16 years. For both NHA and NHC groups, the participant's hearing was screened to 20 dBHL across frequencies from 500 Hz to 4 kHz. Individuals volunteering for the NH groups who did not pass the initial hearing screening were referred to an Audiologist and were excluded from the NH groups in the study.

The adult hearing aid users were recruited through an invitation letter sent to the clients of the University of Canterbury Hearing Clinic and to several hearing clinics located around the Christchurch area (see Appendix 1). The subject inclusion criteria for the HA group were that they (1) be native speakers of NZ English or have been speaking NZ English for more than 10 years, (2) be above 18 years of age, (3) have a bilateral SNHL in the mild-to-moderate category or moderately-severe to profound category, (4) be bilateral hearing aid users who have been using HAs for more than a year, (5) have no cognitive, neurological or physical impairment that would impede their ability to understand test-instructions, and (6) have access to a computer at their home or the ability to travel to the University of

Canterbury to take part in the training program. Those who acquired bilateral SNHL before the age of five years were excluded from the study.

The CIA participants were recruited from the Southern Cochlear Implant Adult Program, Christchurch, New Zealand. The CIA participant inclusion criteria was similar to the HA criteria, except that they needed to have been using a CI for more than one year. Those who acquired bilateral SNHL before the age of five years were excluded from the study. The prelingually deafened children who use cochlear implants (CIC) were recruited from the Southern Cochlear Implant Pediatric Program. For the CIC group, the subject inclusion criteria were similar to that of the CIA except for the age, which was 12-18 years.

Participants assigned to V1T included eight CIA (one male & seven females; M = 60 years), 10 HA (eight males & two females; M = 62 years), and three CIC participants (all males; M = 16 years). The control group consisted of both hearing impaired and normal hearing participants. The hearing impaired control group consisted of eight CIA (three males & five females; M = 56 years), 10 HA (six males & four females; M = 66 years), and three CIC participants (one male & two females; M = 14 years. The normal controls included 19 NHA (eight males & 11 females; M = 29 years), and 12 NHC participants (four males & eight females; M = 15 years).

Participants assigned to V2T included eight CIA (three males & five females; M = 56 years), seven HA (four males & three females; M = 65 years), and two of the CIC controls (one male & one female; M = 15 years). The participants who took part in V2T originally served as hearing impaired controls for V1T. Due to time constraints, only a smaller number of participants were included in V2T and there was no control group for V2T. The general characteristics of the CIA, HA, and CIC participants are shown in Tables 1 to 3, respectively.

Prior to participating in the study, all of the hearing impaired participants (trainees & controls) completed a short questionnaire regarding their musical background. Four different versions of the ‘Musical Background’ questionnaire were developed to cater to each group. The CIA participants received Version A (see Appendix 4), the HA participants received Version B (see Appendix 5), the CIC group received Version C (see Appendix 6), and the CIC-parent group received Version D (see Appendix 7). The information gathered from this questionnaire was used to gain an in depth understanding of the musical background of the participants.

Table 1. Participant details of adult cochlear implant recipients (CIA), including those who underwent the Version 1 Training ('V1T') and those who served as the controls for V1T and later underwent the Version 2 training (V2T).

Participant number	Category	Gender	Type of stimulation	Age	Etiology	Duration of any hearing loss pre CI (years)	Type of CI	Ear Implanted	Time With CI (Years)	Speech processor	Hearing aid used in the contra-lateral ear	Speech processing strategy	Rate: Pulses per second (pps)
1	V1T control & V2T	F	Bimodal (CI and a HA in the contra lateral ear)	22	Pre-term birth, Cerebral Palsy with progressive hearing	15	Sonata TI 100	Right Ear	1	Opus 2	Phonak Sonoforte P2 BTE in the Left Ear	FSP	Channels 1to 5: 6000 Channels 7-12: 750
2	V1T control & V2T	M	CI-Only	80	Otosclerosis	50	CI24RCA (channel 18 switched off)	Right Ear	1	Freedom	None	ACE	900
3	V1T control & V2T	M	CI-Only	61	Progressive SNHL and suspected Ototoxicity	49	CI24RCS	Right Ear	5.3	Freedom	None	ACE	900
4	V1T control & V2T	F	CI-Only	49	Maternal Rubella	42	CI24RCS	Right Ear	5	Esprit 3G	None	ACE	1200
5	V1T control & V2T	F	Bimodal	75	Hereditary deafness	2	CI24RCA	Right Ear	3.9	Freedom	Widex Senso Diva BTE in the Left Ear	ACE	900
6	V1T control & V2T	F	CI-Only	52	Details not available	7	CI24RCA	Right Ear	5.2	Esprit3G	None	ACE	900
7	V1T control & V2T	M	Hybrid EAS and Bimodal	73	Hereditary deafness	32	CI24RE Straight/ L 24 Hybrid	Right Ear	1	Freedom	Siemens Centra Power BTE in the Left Ear	ACE	900

Table 1 continued. (Participant details, CIA)

Participant number	Category	Gender	Type of stimulation	Age	Etiology	Duration of deafness pre CI (years)	Type of CI	Ear Implanted	Time With CI (Years)	Speech processing strategy	Hearing aid used in the contra-lateral ear	Speech processing strategy	Rate: Pulses per second (pps)
8	V1T control & V2T	F	Bimodal	42	Turner's Syndrome-progressive bilateral SNHL	25	Sonata TI 100	Right Ear	1.9	Opus 2	Widex Senso Diva ITE in the Left Ear	FSP	715
9	V1T	F	CI-Only	60	Bilateral profound SNHL secondary to meningitis and complete ossification of the cochlea	54	Nucleus 24 double array (channels 5-11 are active, rest are switched off)	Left Ear	6.6	Esprit 3G	None	ACE	900
10	V1T	F	CI-Only	45	Hereditary deafness	25	CI24RCS	Right Ear	8	Freedom	None	ACE	1200
11	V1T	M	Bimodal	84	Progressive SNHL due to unknown causes	44	CI24RCA	Right Ear	3	Freedom	Widex Senso C8 BTE in the Left Ear	ACE	900
12	V1T	F	CI-Only	60	Progressive SNHL due to unknown causes	30	CI24RCA Electrode 21, 22, 1, 2, and 3 are switched off	Right Ear	14	Freedom		SPEAK	250
13	V1T	F	CI-Only	77	Hereditary deafness	41	CI24RCA	Right Ear	4.9	Freedom	None	ACE	900

Table 1 continued. (Participant details, CIA)

Participant number	Category	Gender	Type of stimulation	Age	Etiology	Duration of deafness pre CI (years)	Type of CI	Ear Implanted	Time With CI (Years)	Speech processing strategy	Hearing aid used in the contra-lateral ear	Speech processing strategy	Rate: Pulses per second (pps)
14	V1T	F	CI-Only	49	Hereditary deafness	37	CI24RCA	Left Ear	2	Freedom	None	ACE	900
15	V1T	F	CI-Only	54	Progressive SNHL due to unknown causes	48	SONATA TI 100	Right Ear	1	Opus 2	None	FSP	900
16	V1T	F	Bimodal	62	Progressive SNHL due to unknown causes	34	CI24RCA	Left Ear	5.3	Esprit 3G	Widex Senso Diva BTE in the Right Ear	ACE	900

Table 2. Participant details of adult hearing aid users (HA), including those who underwent V1T, those who served as the controls for V1T only, and those who served as the controls for V1T and later underwent V2T.

Participant number	Category	Gender	Type of Hearing Loss	Age	Etiology	Name of the HAs used in both ears	Average number of hours HA worn in the RE per day	Average number of hours HA worn in the LE per day	PTA Right ear (dB)	PTA Left ear (dB)	Duration of the HAs used in left ear (years)	Duration of HAs used in right ear (years)
17	V1T control & V2T	M	Bilateral Mild to Moderately Severe sloping SNHL	63	NIHL	Next 16 Moxi mini BTE (Unitron)	14	14	28.33	38.33	2	2
18	V1T control & V2T	F	Bilateral Moderate to Severe SNHL	69	Hereditary HL	Safran BTE (Oticon)	13	13	43.33	43.33	3	10
19	V1T control & V2T	M	Bilateral Mild to Moderately Severe SNHL	58	NIHL	Passion PA(Widex)	4	4	21.66	25	1.5	1.5
20	V1T control & V2T	M	Bilateral Mild to Moderate SNHL	69	Unknown	Versata M (Phonak)	10	10	23.33	28.33	2.8	2.8
21	V1T control & V2T	F	Right Ear: Moderate to Moderately Severe SNHL Left Ear: Mild to Moderately Severe SNHL	60	Unknown	Audeo (Phonak)	8	8	45	25	1.4	1.4

22	V1T control & V2T	F	Bilateral Moderately Severe SNHL	62	Ototoxicity and Cochlear dead regions between 500 to 2000 Hz	Passport BTE (Unitron)	14	14	63.33	70	1	1.3
23	V1T control & V2T	M	Bilateral Mild to Moderately Severe SNHL	76	NIHL	Resound plus 5 BTE (GN Resound)	12	12	33.33	36.67	3	3
24	V1T control only	F	Bilateral Mild to Moderately Severe SNHL	70	Unknown	Hi Pro RITE BTE (Oticon)	12	12	36.67	35	1.6	1.6
25	V1T control only	M	Bilateral Mild to Moderately Severe SNHL	71	Hereditary HL	Indigo Moxi Mini BTE (Unitron)	4	4	35	25	3	2.1
26	V1T	F	Bilateral Moderate SNHL	41	Hereditary HL	Next 16 (Unitron)	15	15	45	41.67	2	2
27	V1T	M	Bilateral normal hearing in low-mid frequencies with Mild to Moderate sloping SNHL in mid to high frequency region	63	Unknown	Passion PA 110 (Widex)	6	6	16.67	11.67	1.5	1.5

28	V1T	F	Bilateral Mild to Moderately Severe SNHL	75	Unknown	Aikia AKM Micro BTE (Widex)	5	5	26.67	26.67	1.5	1.4
29	V1T	M	Bilateral Moderate to Moderately Severe SNHL	77	Unknown	Element 16 ITE (Unitron)	12	12	41.67	40	1.3	1.3

Table 2 continued. (Participant details, HA)

Participant number	Category	Gender	Type of Hearing Loss	Age	Etiology	Name of the HAs used in both ears	Average number of hours HA worn in the RE per day	Average number of hours HA worn in the LE per day	PTA (average of 500Hz, 1kHz and 2 kHz) Right ear (dB)	PTA (average of 500Hz, 1kHz and 2 kHz) Left ear (dB)	Duration of the HAs used in left ear (years)	Duration of HAs used in right ear (years)
30	V1T	M	Bilateral normal hearing in low to mid frequencies and Mild to Moderately Severe SNHL high frequencies	62	Unknown	Metrix mini BTE (GN Resound)	13	13	15	13.33	4	4
31	V1T	M	Right Ear: Moderate to Severe SNHL Left Ear: Severe SNHL	47	Hereditary HL	Epoq XW RITE Power (Oticon)	15	15	48.33	85	7	7
32	V1T	M	Bilateral Mild to Moderate SNHL	53	Progressive HL	Artis Life (Siemens)	12	12	36.67	36.67	3.5	3.5
33	V1T	F	Bilateral Mild to Moderately Severe SNHL	72	NIHL	Flash FL-9 Elan (GN Resound)	16	16	30	26.67	1	1.3
34	V1T	M	Right Ear: Mild to Moderate SNHL	67	NIHL	Micro Savia BTE (Phonak)	12	12	31.67	20	3.5	3.5

			Left Ear: Mild to Moderately Severe sloping SNHL									
35	V1T	M	Right Ear: Mild to Moderately Severe SNHL Left Ear: Moderate to Moderately Severe SNHL	69	NIHL	Intuis BTE (Siemens)	4	4	38.33	45	2	2
36	V1T control only	M	Bilateral Mild to Moderately Severe SNHL	71	Unknown	Micro Power BTE (Phonak)	4	4	33.33	40	1.5	1.5

Table 3. Participant details of pediatric cochlear implant recipients (CIC), including those who underwent V1T, those who served as the controls for V1T only, and those who served as the controls for V1T and later underwent V2T.

Participant number	Category	Gender	Age	Etiology	Type of CI	Speech processor	Speech processing strategy	Age at which the HL was diagnosed (years)	Age at which the HAs were fitted (years)	Age at which the child was implanted (years)	Ear implanted
37	V1T control & V2T	F	14	Gestational diabetes	CI24RM-Nucleus 24	Esprit3G	SPEAK	3	3	3.6	Right
38	V1T control & V2T	M	16	Details not available	CI24M-Nucleus 24	Esprit3G	ACE	4	6	6.4	Right
39	V1T control only	F	12	Maternal rubella at 1st week of pregnancy and Toxemia from 26-30 week, premature birth at 34 weeks,	CI24RECA	Freedom	ACE	1.3	1.3	2.5	Right
40	V1T	M	16	Gentamycin	CI24 RST	Freedom	ACE	0.9	1.3	7.8	Right
41	V1T	M	17	Mondini dysplasia	CI24RM-Nucleus 24	Freedom	ACE	2.5	3	3.6	Left
42	V1T	M	16	High fever and seizure	CI24 RM-Nucleus 24	Freedom	ACE	2.5	4	4.2	Right

3.3 Test Materials and Questionnaires

The testing protocol developed for this study included (1) objective tests to evaluate the pitch-related speech and music perception skills, and (2) a questionnaire to obtain the participants' feedback regarding the training program.

3.3.1 Tests of Speech and Music Perception

This section describes the test battery that was used to evaluate the participant's pitch-related speech and music perception. A combination of standardized and specifically-developed test materials was used. A review of the literature failed to identify any test materials suitable for evaluating the pitch-related speech and music perception skills of New Zealand English speakers. Therefore, five tests were developed: (1) an emotion identification test, (2) a question/statement identification test, (3) a familiar melody identification test with and without rhythm, (4) a familiar musical instrument identification test, and (5) a pitch ranking test. Each of these tests is described in detail below.

(1) CUNY Sentence and CNC-Phoneme and Word Identification Tests

To assess the general speech perception skills of the participants, two sets of standardized speech-in-noise test materials were administered: (1) The City University of New York (CUNY) sentence identification test (Boothroyd, Hanin, & Hnath, 1985) and (2) CNC-phoneme and word identification tests (Lehitse & Peterson, 1959). All these test materials were standardized to use with four-talker babble. Ten test items were selected from the CUNY test. Twenty-five test items (half-list) were selected from each of the CNC-word and CNC-phoneme identification tests.

(2) Emotion Identification Test

To develop the stimuli for the ‘emotion identification’ test, eight semantically neutral utterances were selected by a panel of linguists. The panel consisted of five linguists (two academic staff members & three PhD students) who were staff at the Department of Linguistics at the University of Canterbury. Panel members were asked to select utterances that were context-free (i.e., did not require a context to maintain their meanings) from a list of 22 everyday sentences used by New Zealanders. The following eight sentences were selected to be used as the stimuli for the emotion identification test.

- She is coming home
- I just sold my car
- I’m going home
- We’re watching rugby
- They got back together
- They are getting married
- It’s snowing outside
- It’s raining outside

The production of these eight utterances were then audio recorded by two male and two female actors, aged between 18-24 years (M = 21 years, SD = 3) who were recruited from the University of Canterbury Film and Theatre Studies Department. Each actor produced the eight semantically neutral utterances using four target emotions (Angry, Happy, Sad, and Neutral). During the recording, the actor was seated in front of a microphone (Sony ECM-MS907) mounted on a stand at a mouth-to-microphone distance of approximately 30 cm. The speaker was instructed to imagine a real life situation and say the sentences with the given target emotion. Three trials were recorded for each target emotion. Recordings were made in a sound treated room via an audio recorder (Sony HiMD N50) using the PCM (Pulse-Code Modulation) mode. The sampling rate was 44,100 Hz, with a 16-bit resolution. The digitized signals were subsequently edited to segment-out each sentence and intensity was normalized using Adobe Audition (Version 5).

A total of 384 sentences (4 speakers X 8 sentences X 4 emotions X 3 trials) were recorded. These sentences were then pilot tested on 20 normal hearing participants in a sound treated room. Sentences were presented in two sessions, using a special software program (UC-PSR) installed in a laptop computer (Toshiba PTA71A-012003) via a loudspeaker (JBL Ti100), to each of the listeners. The percentage of the participants who identified the sentence as the target emotion was calculated for each sentence. The sentences that were not recognized as the correct emotion by at least 80% of the listeners were removed from the test items. From the remaining total, 72 test items were randomly chosen. These items were further subdivided to form a pre-training test sample of 24 test items (12 utterances from the female voices and 12 from the male voices), as well as a post-training test 1 of sample of 24 items (following V1T) and a post-training test 2 sample of 24 items (following V2T).

(3) Question/Statement Identification Test

The same linguists, actors, recording and playback systems used in the development of the ‘emotion identification’ test were employed for developing the ‘question/statement identification’ test. Firstly, 28 semantically neutral utterances were listed by the linguists. For the acoustic recording, the actors were instructed to read aloud all of the 28 sentences as if they were asking a question, and then as if they were making a declarative statement. A total of 112 sentences were recorded (28 sentences X 2 speakers X 2 conditions) which were then pilot tested with 20 NH listeners. The same selection criterion as described for the ‘emotion identification’ test was used to yield 24 test items (12 utterances from the female voices and 12 from male voices). The 12 utterances used in the ‘emotion identification’ test were shown as follow.

- Everybody/Everyone
- The green pencil case
- A cup of coffee
- The red apple
- The tall one
- Two cups of tea
- A rusty nail
- The world cup
- More sugar
- One hundred and thirty-three
- My ex-boy friend
- My mum/my nana

(4) Familiar Melody Identification Test with and without Rhythm

Prior to the development of the ‘familiar melody identification’ test, a survey questionnaire was developed and then administered to 100 New Zealanders to identify songs that were familiar to them. The purpose of this survey was to identify a list of melodies that were most familiar to New Zealanders, not only for developing the stimuli for use in the ‘familiar melody identification’ test, but also for constructing the ‘familiar melody identification’ questionnaire to be administrated to the participant groups of the main experiment in this study. Based on the results obtained from the survey, a list of 44 most familiar songs were included in the ‘familiar melody identification’ questionnaire to be administered to all of the five participant groups (NHA, NHC, HA, CIA, and CIC) in the main experiment of the study (see Appendix 8).

The test stimuli for the ‘Familiar melody identification’ test were generated by recording the first 15-second segment of the chorus of each of the 44 selected melodies. These were played by a professional musician on a Yamaha grand piano. Each melody was played in C major (centered on middle C/C4) incorporating F0 range of C3 (130.81 Hz)-C6 (1046.5 Hz). The melody was played in two ways: with the original rhythm and without rhythm (i.e., all the musical notes were played using equal duration notes. A condenser microphone (ECM-MS907) and a portable mini-disk recorder (MZ-RH1) were used for acoustic recording. The signals were recorded in an uncompressed linear PCM format and later converted to a ‘.Wav’ format by using the Adobe Audition software. The last five seconds of each of the 15-second melody segments was linearly ramped to zero amplitude.

(5) Familiar Musical Instrument Identification Test

Similar to the procedure used to develop the ‘familiar melody identification’ test, a ‘familiar musical instrument identification’ questionnaire was initially administered to normal hearing and hearing impaired individuals to identify the musical instruments to be included in the test. The questionnaire enlisted 14 commonly used musical instruments: Piano, Church Organ, Guitar, Cello, Violin, Trumpet, Marimba, Glockenspiel, Flute, Clarinet-Bass, Clarinet-Treble, Saxophone-Baritone, Saxophone-Tenor, and Saxophone-Soprano, encompassing the main musical instrument families of Keyboard, String, Brass, Woodwind, and Percussion. The questionnaire was designed to identify the musical instruments that participants ‘did not know’, those they ‘knew the name of’, and those they ‘could recognize when they heard the instrument’ (see Appendix 9).

Based on the findings from the aforementioned questionnaire, two musical instruments from each category of woodwind, brass, percussion, keyboard, and string were selected for use in the ‘familiar musical instrument identification’ test. The selected musical instruments were: Clarinet-Bass, Clarinet-Soprano, Flute, Trumpet, Saxophone-Tenor, Saxophone-Baritone, Saxophone-Soprano, Glockenspiel, Piano, Church Organ, Violin, and Cello. Frequency ranges for each of these instruments are shown in Appendix 10. The same recording procedures as used for the 'familiar melody identification' test were followed. All of the instrument recordings were made in a sound treated room except for Church Organ, which was recorded in an empty hall. All of the recordings (except for Church Organ) were maintained at an 80 dBA level, as measured by the sound level meter placed at 1m away from the sound source. The Church Organ recordings were maintained at a 90 dBA level at 6m away from the sound source. Professional musicians were recruited to play the musical instruments for recording. Each musician was instructed to play a chromatic scale from the lowest to highest note that could be played, with each note to be sustained for at least 500 msec at a constant sound pressure level. The microphone was placed 1m away from the sound bore of the instrument. Three recording sequences were taken for each instrument.

Using the Adobe Audition software, each recorded signal was edited to be 500 msec long, with a 30-msec fall time and normalized to 65 dBSPL. The intensity of the stimuli was further changed with a random variation of ±6 dB to reduce any potential effect of loudness on pitch perception tasks. For woodwind and brass instruments, the inherent hiss (breathing noise of the players while playing the instrument) was reduced by using the 'hiss reduction' feature available in the software. The attack time of the instrumental recordings was maintained in order to preserve the original quality and timbre characteristics of the signal. An ascending/descending scale for each musical instrument was used in the 'familiar musical instrument identification' test.

(6) Pitch Ranking Test

To generate the stimuli for use in the 'pitch ranking' test, a 23-year old native New Zealand English female speaker, who had more than five years of formal singing training was recruited. She was seated in a sound treated room for the acoustic recording. The singer's task was to sing /a/ without vibrato at a constant loudness level for approximately six seconds after listening to a tone played on a portable keyboard (Yamaha PSR 275). The same recording system and sound level meter used in recording the stimuli for the ‘familiar melody identification’ and ‘familiar musical instrument identification’ tests were used in recording the stimuli for the ‘pitch ranking’ test. All of the sung vowels were recorded at a 65 dBA as measured by the sound level meter. The microphone was mounted on a stand and placed in front of the singer at a distance of 1m away from the lips. The signals recorded ranged in frequency from F3 (175 Hz) to G6 (1568 Hz). Each signal was edited to have 500-msec duration, with 30-msec rise and fall times, and normalized to 65 dBA. The loudness of the stimuli was further changed with a random variation of ±6 dB to reduce the potential effect of loudness on the performance in the ‘pitch ranking’ test. A total of 24 sung vowels of varying pitch were selected.

3.3.2 Post-Training Evaluation Questionnaires

The post-training evaluation questionnaire was designed to find out the efficacy of the training program and the views of the participants about the training program, as well as to identify possible changes that would be made to the current program for future use. Three versions of this questionnaire were designed. Version A was to identify the views of the CIA and HA participants (see Appendix 11). Version B was for the CIC participants (see Appendix 12), and Version C was for the parents of pediatric CI participants (see Appendix 13). All three versions contained similar questions appropriately worded to suit the target population.

3.4 Pre- and Post-Training Test Procedures

All test stimuli were presented using a laptop computer (Toshiba PTA71A-012003) with the Windows XP platform connected to a graphic equalizer DBX 231). Participants were asked to use their hearing device (CI/HA) with their everyday settings. They were seated directly in front of a loudspeaker (JBL Ti100). Test sessions were of one-hour duration, and breaks were given to participants as required. Before each testing session, the loudspeaker (JBL Ti100) was calibrated at 65 dBA level using a sound level meter (1 dB Solo Sonometre). Precautions were taken not to repeat the same stimulus in the pre-training, post-training test 1, and post-training test 2 conditions to minimize the task-related learning effect. All the testing were carried out in a sound-treated room.

(1) CUNY and CNC-Phoneme and Word Identification Tests

For the CUNY-sentence identification test, 10 sentences were presented with for-talker babbly noise to all of the participants at 10 dB SNR. For the CNC-phoneme and word identification tests, 25 test items for each of the two tests were presented at 10 dB SNR. The total scores obtained by each participant for the sentence, phonemes, and word stimuli were calculated separately and converted into percent-correct scores.

(2) Emotion Identification Test

Twenty- four test items were randomized and presented via a locally developed software program written using LabVIEW Version 8.20 platform (National Instruments, Texas, USA). Participants were instructed to listen to each utterance, identify the underlying emotion of the speaker and mark their response on the computer touch screen as ‘happy’, ‘sad’, ‘angry’, or ‘neutral’ emotion (see Figure 3). Percent-correct scores were calculated separately for the male and female voices and for the combined scores for both male and female voices.

Figure 3. A screen display presented to prompt the user to identify the emotion associated with a spoken utterance.

(3) Question/Statement Identification Test

For the ‘question/statement identification’ test, the 24 test items were randomized and presented via a locally developed software program written using LabVIEW Version 8.20 platform (National Instruments, Texas, USA). The participants were asked to listen to each utterance and mark their response on the computer touch screen identifying the sentence as a question or a statement (see Figure 4). Percentage scores were calculated separately for male voice, female voice, and combined results for both male and female voices.

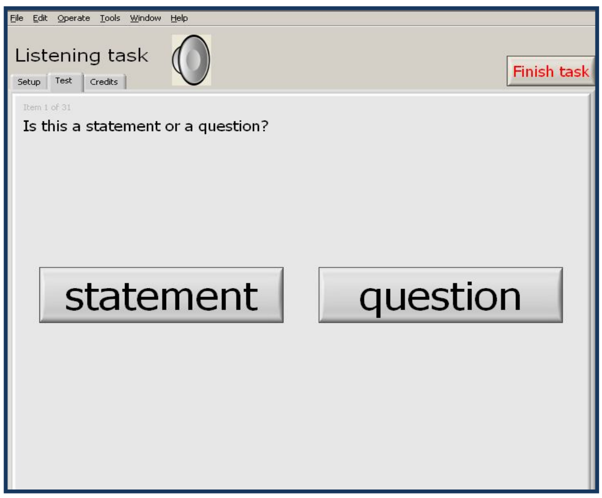

Figure 4. A screen display presented to prompt the user to indicate whether the spoken utterance is a question or a statement.

(4) Familiar Melody Identification Test

Based on results obtained from the 'familiar melody identification' questionnaire, songs identified as 'familiar' by each participant were entered into a locally developed software program written to deliver the test stimuli (using the LISP programming language and Tk inter-phasing toolkit and sounds were presented using the '.net' platform). Participants were tested only on the songs that they previously identified as 'familiar". For the pre-training test condition, ten familiar melodies were randomly selected and presented to each participant. Five songs were presented with rhythm and the remaining five were presented without rhythm using a four-alternate-forced-choice (AFC) paradigm. Participants were asked to select the correct answer from a choice of four presented on the screen (see Figure 5). All of the ten melodies were presented twice for a total possible score of 20. This score was then converted into a percent-correct score for each participant. For the post-training test condition, another set of ten songs were selected. Songs that were used for the pre-training test condition were not selected for the post-training test conditions.

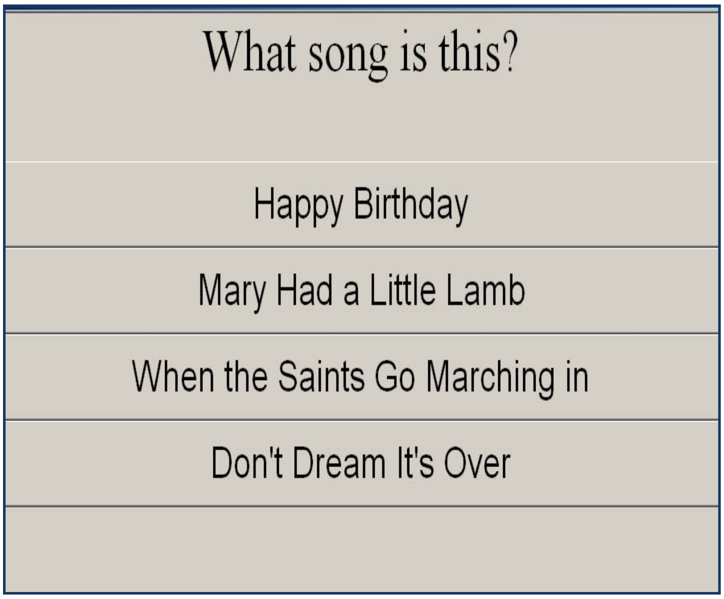

Figure 5. Example of a screen display presented to elicit a response from the user in the 'familiar melody identification' test.

(5) Familiar Musical Instrument Identification Test

This test used a procedure that was similar to the 'familiar melody identification test'. From the results obtained from the familiar musical instrument identification questionnaire, instruments that were identified as 'familiar' by each participant were entered into the program. The pre-training test condition automatically selected the ascending scales of the familiar instruments and each instrument was tested twice in a random order. A four-alternative forced choice (4-AFC) paradigm was used where participants selected their choices on the test screen (see Figure 6). Scores were calculated and the final score was converted into a percentage. The same procedure was followed for the post-training test conditions.

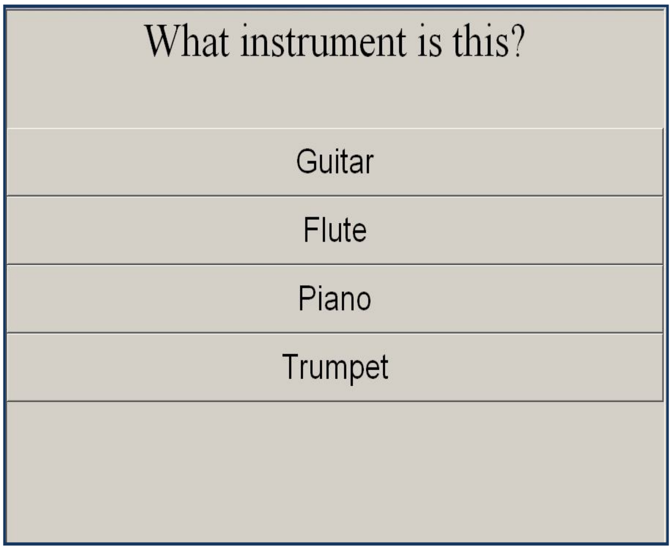

Figure 6. Example of a screen display presented to elicit a response from the user in the 'familiar musical instrument identification' test.

(6) Pitch Ranking

A total of 24 pairs of sung vowels of varying pitch were randomly selected and played to the participants. Each note in the pair was separated by a gap of 500 msec, with the distance randomly varied between one to 12 semitones (12 semitones = 1 octave). Two examples for each semitone separation level were presented to each participant. The participant's task was to identify the tone that was higher in pitch and select the appropriate answer on the computer touch screen (see Figure 7). The 2AFC paradigm was used and the percent-correct score was calculated.

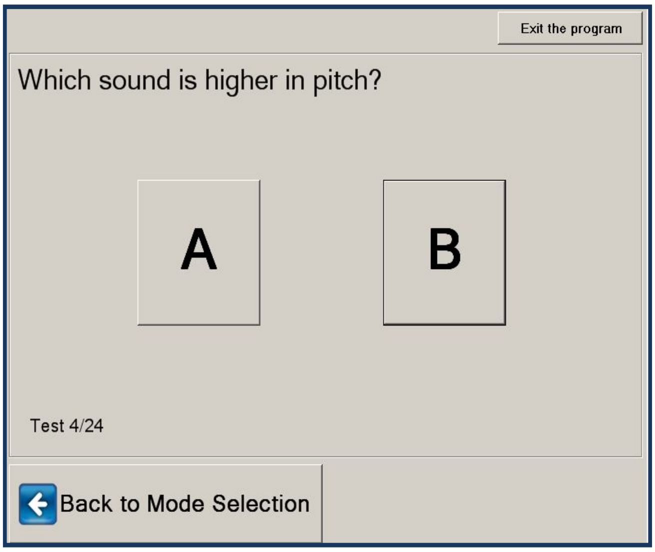

Figure 7. A screen display presented to elicit a response from the user in the 'pitch ranking' test.

3.5 Training Program

The computerized pitch-perception training program developed in this study differs from existing music training programs in four major aspects. Firstly, the stimuli used in the program are natural recordings of human voices and notes are played with real musical instruments (non-synthesized). The human voices included female and male sung vowels /a/,

/ae/, /i/, /o/, /u/. The 13 instruments used in this program were: Clarinet-Bass, Clarinet-Soprano, Flute, Trumpet, Saxophone-Tenor, Saxophone-Soprano, Saxophone-Baritone, Glockenspiel, Piano, Church Organ, Guitar, Violin and Cello. Secondly, this program covered a large range of frequencies for different musical instruments and human voices. Frequencies range from 130.81 Hz (male sung vowel /a/, /ae/, /i/, /o/, /u/) to 1108.73 Hz (female /u/) for the human voice and 146.83 Hz (Clarinet-Bass) up to 4698.64 Hz (Glockenspiel) for the musical instruments. Thirdly, this program was implemented as a computer-based program with a variety of interactive activities progressing from simple to complex tasks based on either a predetermined progression sequence (in V1T) or an adaptive scheme in accordance with the trainee's performance (in V2T). Lastly, the program had a data logging module to allow for the examiner to track the trainee's error patterns and training process. There were three main tasks used in this training program:

1. Pitch discrimination: to identify the tone (either musical instruments or sung vowel) with a higher or a lower pitch.
2. Odd-one-out: to identify a tone (either musical instruments or sung vowel) with a different pitch from a set of three tones.
3. Pitch contour: to identify a sequence of five tones (either musical instruments or sung vowel) as flat, up, down, flat-up, flat-down, up-down, up-flat, down-flat, and down-up.

For the pitch discrimination task, two sounds produced with the same musical instrument or singer were presented with a gap of 500 msec in between. For the odd-one-out task, all three tones were presented in a sequence, with a gap of 500 msec. For the pitch contour task, the five tones per contour were presented sequentially with a gap of 500 msec between the adjacent tones. The interval between the notes in each task ranged from one to twelve semitones. Each task started with a twelve semitone separation level for all instruments and descended to the one semitone separation level in a gradual manner according to the program algorithm.

3.5.1 Training Program: V1T

All of the tasks associated with V1T started at the 12 semitone separation level. Once the participant completed all of the examples given at a given level (X), the program gradually descended one step (X-1). This procedure continued until the most difficult level of one-semitone separation was reached. An illustration of the procedures in V1T is shown in Figure 8. For example, if a participant selects to work with the pitch ranking task, he/she will be given stimuli starting from X (X = 12) semitone separation level (i.e., two tones would be 12 semitones apart). After completing all the stimuli listed under the12 semitone separation level, the program will automatically descend one step, and will present stimuli from (X-1) level (i.e., 11 semitone separation level). After completing all of the stimuli listed under 11 semitone separation level, the program will descend one step to the10 semitone separation level. This is repeated until a 1 semitone separation level is reached. After completing all of the stimuli listed at the 1 semitone separation level, the program will automatically stop. However, participants can terminate the program whenever they wish (Figure 8). The training program had a default setting that every time a participant started a new session with a new instrument, the program automatically started from the 12 semitone level.

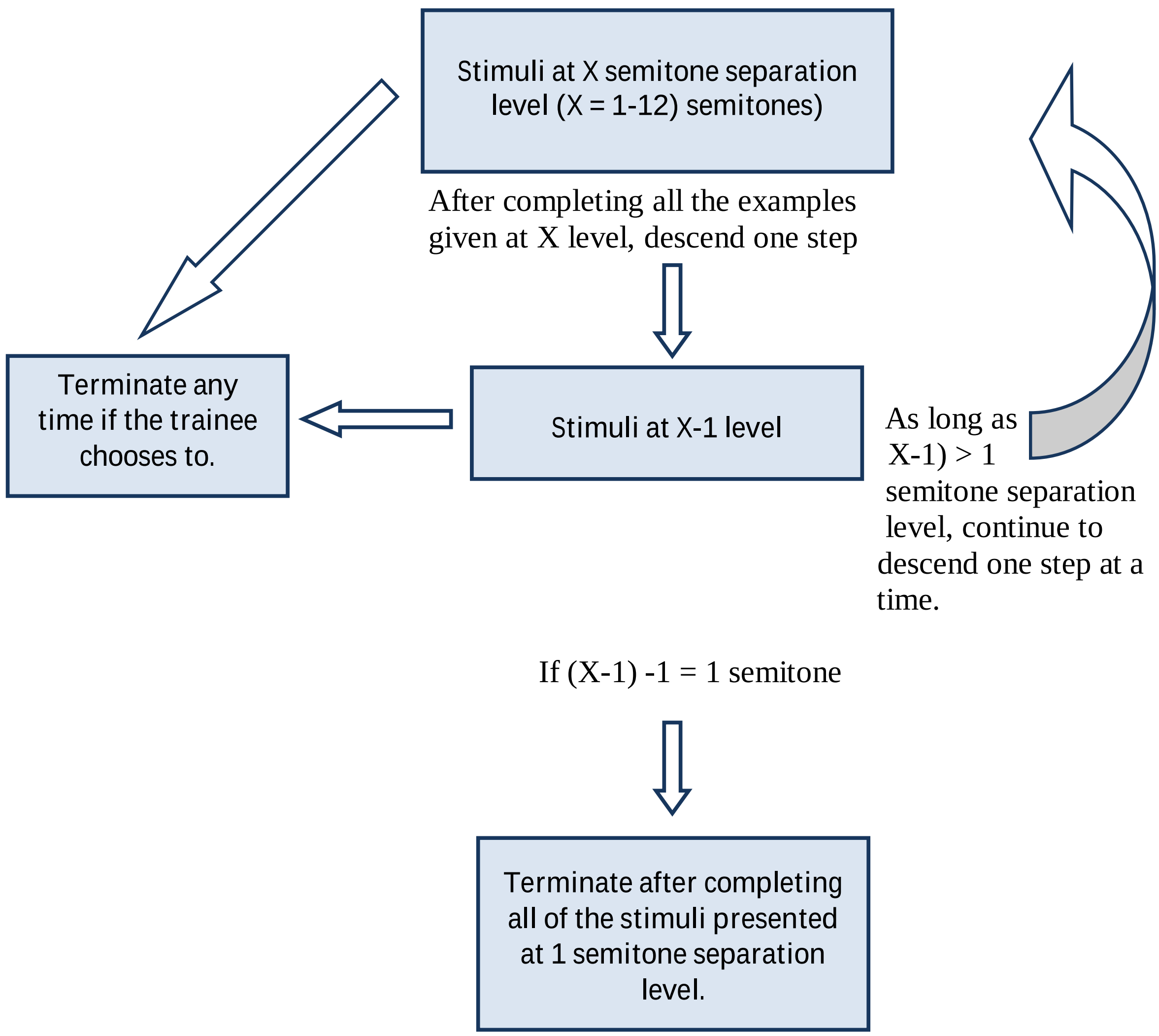

Figure 8. A flowchart illustrating the progression criteria used in the V1T program.

3.5.2 Training Program: V2T

The V2T program differed in a unique way from the V1T program by incorporating an adaptive procedure. This version used an algorithm that controlled the difficulty level of the tasks that were presented to each participant.

As shown in Figure 8, if a participant selected to work with the pitch discrimination task, he/she would be given stimuli starting from X (e.g., X = 12) semitone separation level. If the participant obtained 80% correct at 12 semitone separation level, the program would automatically descend one step and would provide stimuli from (X-1) level (i.e., 12-1 = 11) semitones separation level. As long as the participant obtained 80% correct scores at each semitone separation level, the program would continue to descend one step at a time. This pattern would continue until the most difficult level of one semitone separation is reached. Each session started at a 12 semitone separation level. However, participants could terminate the program whenever they wished. In addition, if a participant obtained 40-80% correct scores at any given (X) semitone separation level (i.e., 10 semitone level), instead of descending one step (X-1), (i.e., 9 semitone level), the program provided more examples at the same X (10) semitone separation level. If a participant obtained less than 40% correct scores at a given level (X), i.e.,10 semitones, the program ascended one step (X+1) level, i.e., 11 semitone separation level. This pattern continued until the person repeatedly received less than 40% scores at a 12 semitone separation level. Once this level was reached, the program terminated (Figure 9). Similar to the V1T program, every time the participant started a new session/trained with a new instrument, the program would start from the 12 semitone level. A training manual was developed and provided to all participants to accompany the training program.

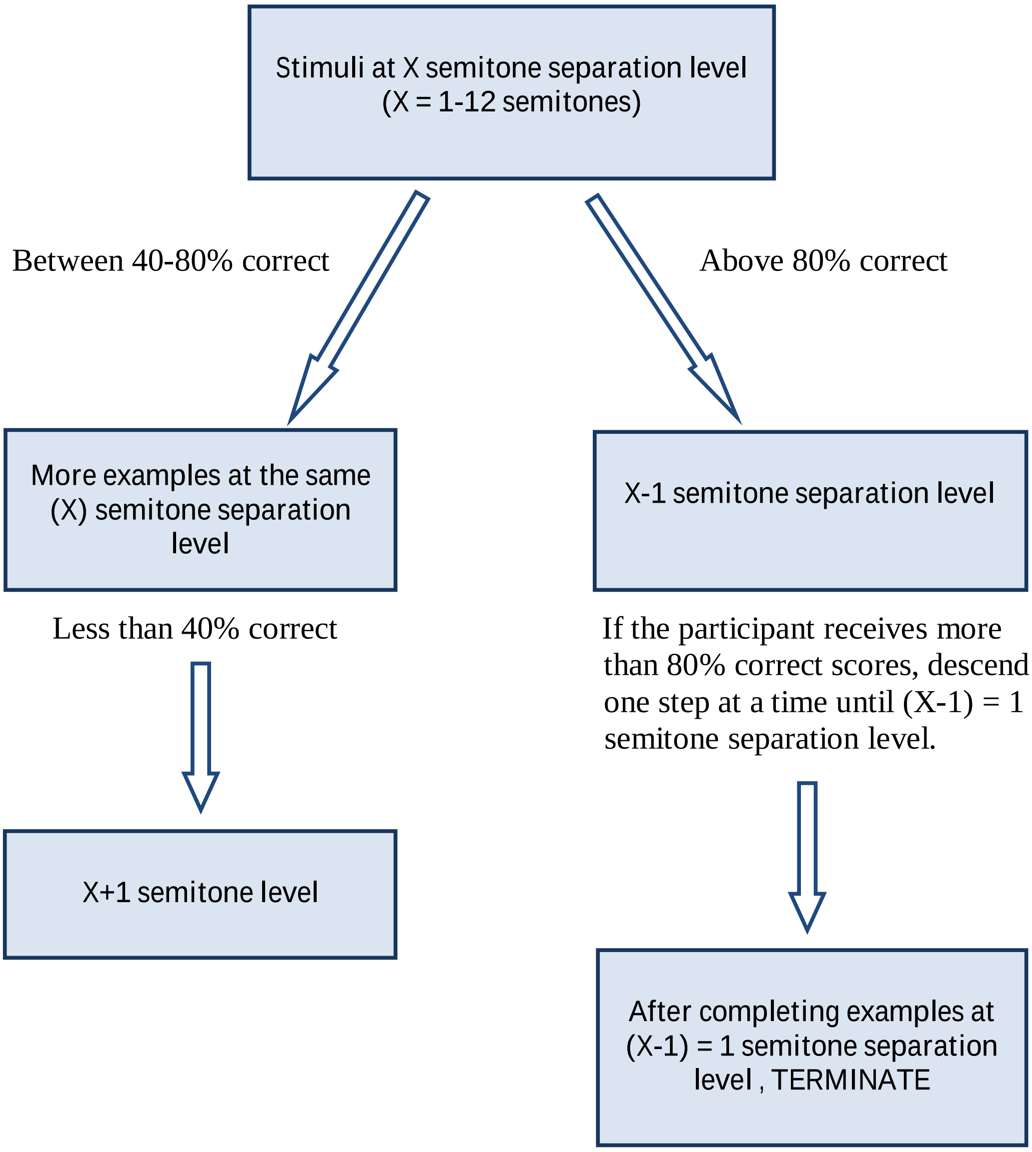

Figure 9. Flowchart illustrating the progression criteria used in the V2T program.

3.5.3 Stimuli

The stimuli used in both versions of the training program included audio recordings of 13 musical instruments and two singers. The musical instrument modules of the program used the same normalized stimuli used in the ‘familiar musical instrument identification’ test. The human voice stimuli of the training program consisted of audio recording of vowels sung by two formally trained singers, one male (aged 24 years) and one female (aged 23 years). The singers were asked to produce each of the vowels /i/, /e/, /a/, /o/, and /u/ after listening to a target note played on the keyboard. Each sung vowel was sustained for approximately six seconds. The singers were given a visual display of the average sound pressure level of their voice and were instructed to keep their voice at a constant pitch and loudness level without using vibrato. Even though the female sung vowel /a/ and the musical instrument notes were used in the pre- and post-training pitch ranking and musical instrument identification tests, precautions were taken not to include the same test stimuli as training stimuli in the training program.

3.5.4 Training Procedure

Following a pre-training test, participants in each training group were given a step-by-step demonstration on how to use the training program. They were instructed to use the program for 30 minutes per day, four days per week for a period of ten weeks and were encouraged to fill in the training log that was provided in the training manual. The program had a data logging feature that recorded the training details for each participant. Participants were asked to select from the list of instruments an instrument that they would like to train with (see Figure 10). The participants were also instructed to select one of three tasks (i.e., pitch discrimination, odd-one-out, and pitch contour) and stay on the task for ten minutes or until completion of the task (see Figure 11). Participants could select the module and task in any order they preferred. For each of three tasks, participants were encouraged to click on the 'play again' button to re-listen to the given stimuli if needed. Once a correct response was given, positive feedback was provided on the screen display. If an incorrect answer was given, the correct answer was provided on the screen display with another opportunity for the trainee to listen to the stimuli as many times as needed.

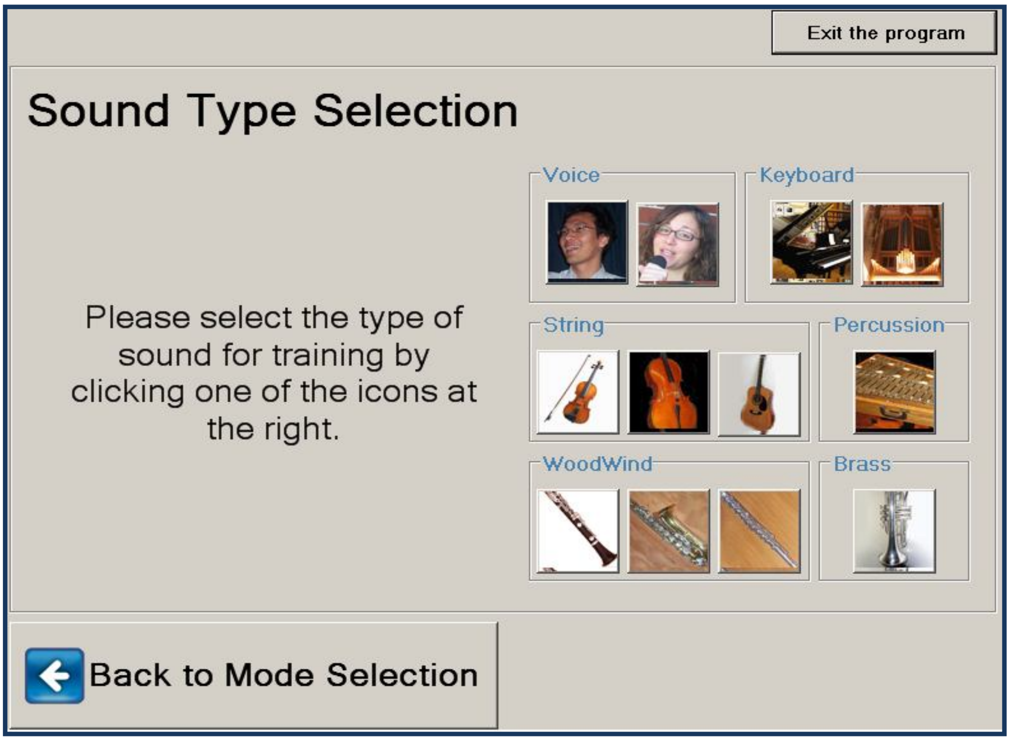

Figure 10. Example of a screen display to prompt the user to select an instrument for training.

Pitch Discrimination Task: A screen was displayed to prompt the participant to select the module for training (see Figure 11). Once selecting the pitch discrimination task, participants were directed to a screen that provided instructions. They were asked to listen to two tones (either musical instruments or sung vowel) and click on the tone that sounded higher in pitch (see Figure 12). Feedback was provided regarding the accuracy of the participant's responses for each presentation (see Figures 13 & 14). If the participant selected an incorrect answer, they were given opportunities to listen to the same presentation as many times as they wished (see Figure 14).

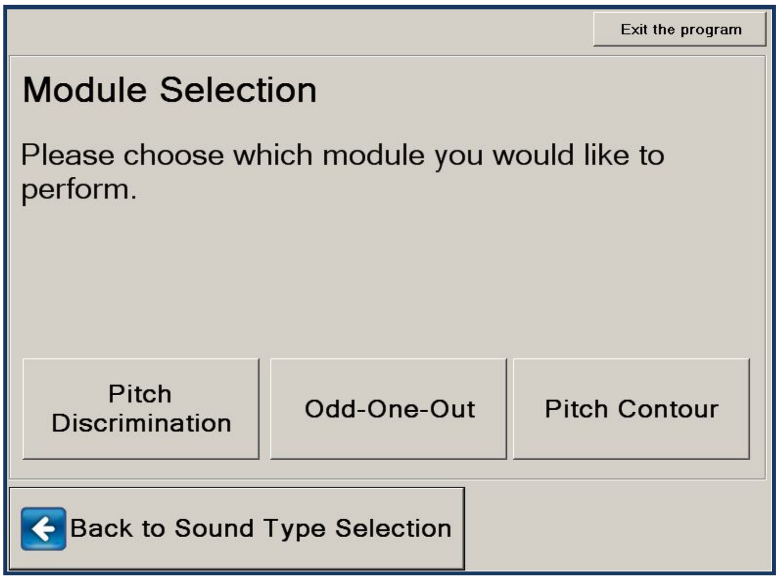

Figure 11. Example of a screen display to prompt the trainee to select a training module.

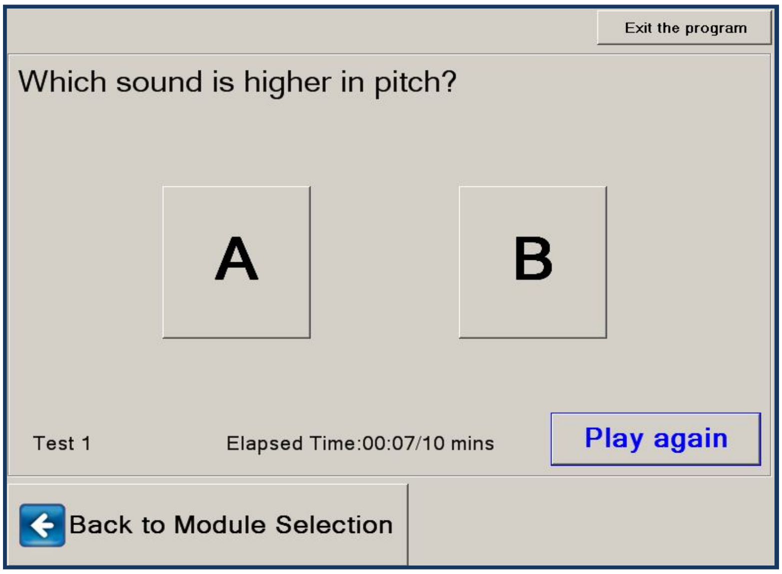

Figure 12. Example of a response screen for the pitch discrimination task.

Figure 13. Example of a feedback screen for selecting the correct answer.

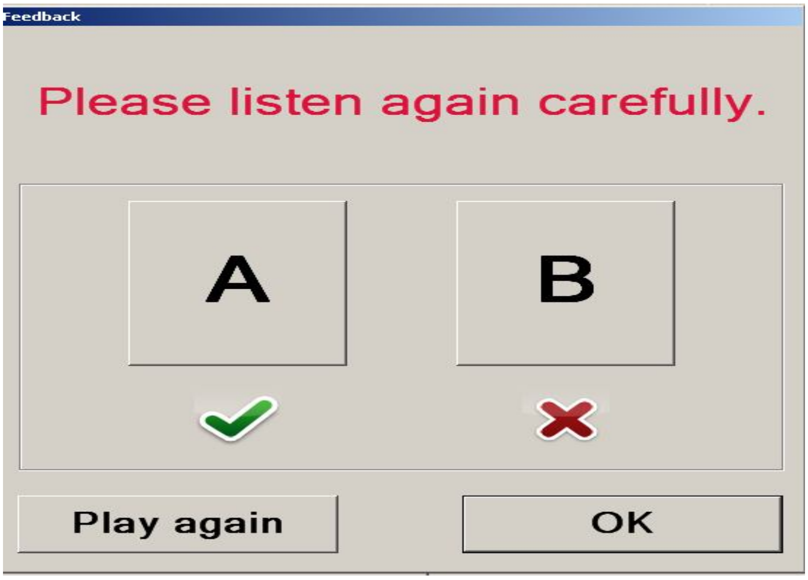

Figure 14. Example of a feedback screen for selecting the incorrect answer.

Odd-One-Out task: When the odd-one-out task was chosen, the trainee was instructed to listen to three tones (either musical instruments or sung vowel) presented in a sequence and click on the tone that sounded different from the other two (see Figure 13).

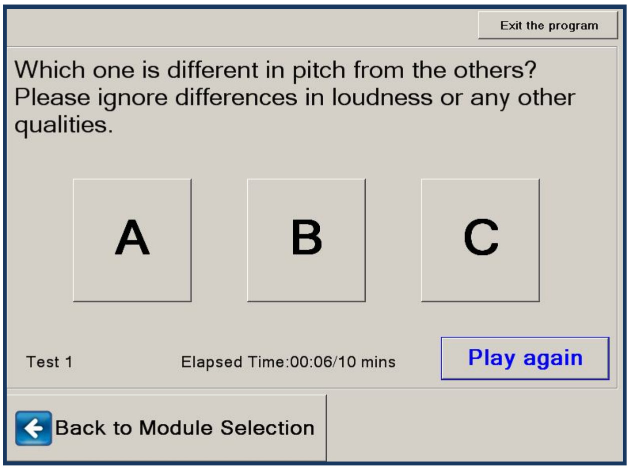

Figure 15. Example of a screen display to elicit a response from the user in the 'odd-one-out' task.

Pitch Contour task: For this task, nine contour patterns were used: Flat up, Flat-Down, Flat, Down-Up, Up, Up-Flat, Down-Flat, Up-Down, and Down (see Figure 16). The 3AFC paradigm was used for stimuli presentation (see Figure 17).

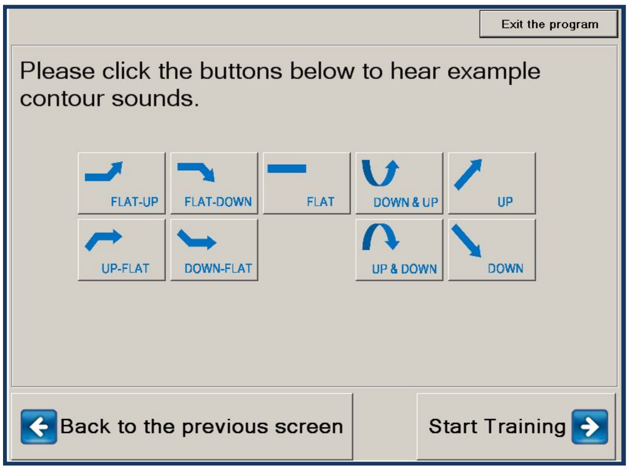

Figure 16. Example of a screen display to familiarize the trainee with the different types of pitch contours included in the 'pitch contour' task.

Figure 17. Example of a screen display to elicit a response from the trainee to the stimuli presented in the 'pitch contour' task.

3.6 Statistical Analysis

Responses to each questionnaire question were tabulated to determine the frequency associated with each ranking category for each participant group. Chi-square tests were conducted to compare distributions of responses across ranking categories. Data retrieved from the data logging feature of the program were summarized in the form of means and standard deviations. The pre-training baseline measures for all of the objective tests included in this study were compared across the five participant groups (NHA, NHC, HA, CIA, and CIC) using a multivariate Analysis of Variances (MANOVAs), followed by a series of univariate ANOVAs and post-hoc pairwise comparison procedures if a significant participant group effect was found. Test scores obtained from the pre- and post-training sessions were compared within each participant group with a paired t-test or sign rank test. The Shapiro-Wilk test was used to test the assumption of normality. The Levene's test was used to test the assumption of homogeneity (i.e., equal variance). In addition, binomial tests were used to determine whether the percent-correct scores obtained from the dichotomous forced choice tasks were higher than chance (one-tailed). A series of Pearson product moment correlation procedures were also conducted to investigate the relationship between a selection of attribute variables or test scores. The significance level was set at 0.05.

Chapter 4: Results

This chapter details results from the various aspects of the development of the training program and the analysis of the pre- and post-training subjective and objective data obtained. Section 4.1 summarizes the survey results from the pre-training musical background questionnaires completed by the three hearing impaired groups. Section 4.2 summarizes results from the objective tests of speech and music perception administered to the participants who completed either V1T (fixed difficulty level) or V2T (adaptive difficulty level) training. Section 4.3 summarizes the data logging information tracked by the training program over the course of the training period. Section 4.4 summarizes the questionnaire results from the post-training program evaluation.

4.1 Pre-Training Musical Background Questionnaires

This section includes the information extracted from the musical background questionnaires filled out by the HA (n = 20), CIA (n = 16), CIC (n = 6) participants, as well as parents of the CIC participants (n = 6). These questionnaire results are organized into five areas: music listening preference, formal music training experience, informal music training experience, ease of performing pitch-related identification tasks, and attendance at music-related activities. Both HA and CIA groups were asked to answer all of these questions. For questions pertaining to formal and informal music training and attendance at music-related activities, the CIC participants were considered to be incapable of providing accurate information and thus answers to these questions were obtained from parents of the CIC participants. As for questions regarding the listening preference of musical styles, answers were obtained directly from the CIC participants

4.1.1 Music Listening Preference

Music listening preferences were assessed in regard to interest in music and the choice of preferred musical style. Interest in music included personal interest and current interest. Personal interest refers to the level at which participants preferred to listen to music in their daily life prior to their hearing loss. Current interest refers to the level at which participants prefer to listen to music with their current hearing device (either CI or HA). Interest level was assessed on a scale from 0 to 10, with 0 indicating 'completely uninterested' and 10 'extremely interested'.

The percentages of participants who listened to different musical styles before hearing loss and after wearing their current hearing devices are shown in Figure 18 for the HA and CIA groups, respectively. All of the HA participants listened to at least one style of music either before or after the hearing loss (see Figure 18b). A small percentage of CIA participants indicated that they did not listen to any musical style before using a hearing device and this percentage increased slightly after wearing a hearing device. The distribution of the listening preferences across different musical styles did not vary significantly by the hearing condition (i.e., before hearing loss vs. wearing a hearing device) for either the HA (χ^2 = 5.409, df = 12, p = 0.943) or the CIA group (χ^2 = 12.037, df = 24, p = 0.979). However, compared to the before-hearing-loss condition, a slight decrease in the percentage of the HA participants could be observed, after receiving HAs, in all musical styles except for Techno and Religious (see Figure 18b). In the CIA group, compared to the before-hearing-loss condition, the wearing-CI condition showed an increase in the percentage of the participants in all musical styles except for Classical Instrumental and Country (see Figure 18a).

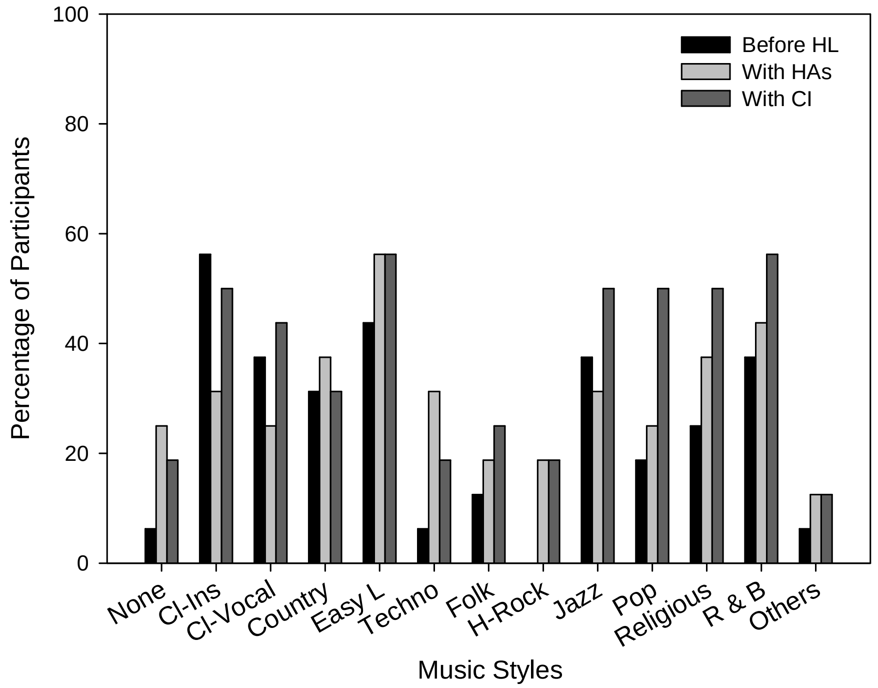

Figure 18a. CIA

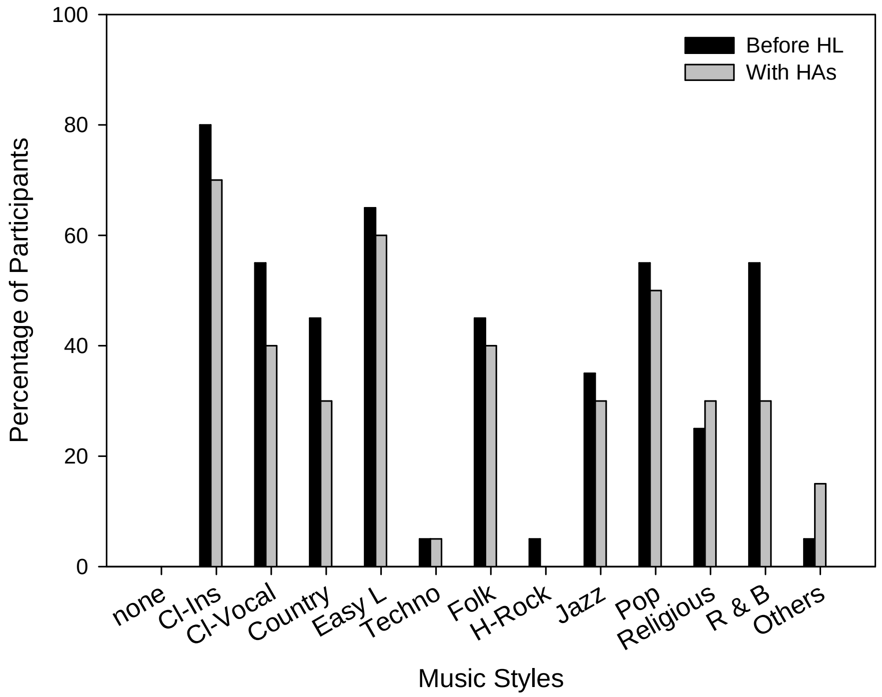

Figure 18b. HA

Figure 18. Percentage of participants across different musical styles, in the CIA and HA groups respectively, before hearing loss (HL) and with their current hearing devices, including hearing aids (HAs) or cochlear implantation (CI).

The percentage of CIC participants who listened to different musical styles with their current hearing devices is shown in Figure 19. The majority of the CIC participants appeared to listen to musical styles with a strong beat, including Pop and Hard-Rock (see Figure 19). In addition, 80% of the CIC participants reported that they could identify their favorite music tunes or recognize their favorite soap opera/drama on TV just by listening to the introductory tune without any visual cues.

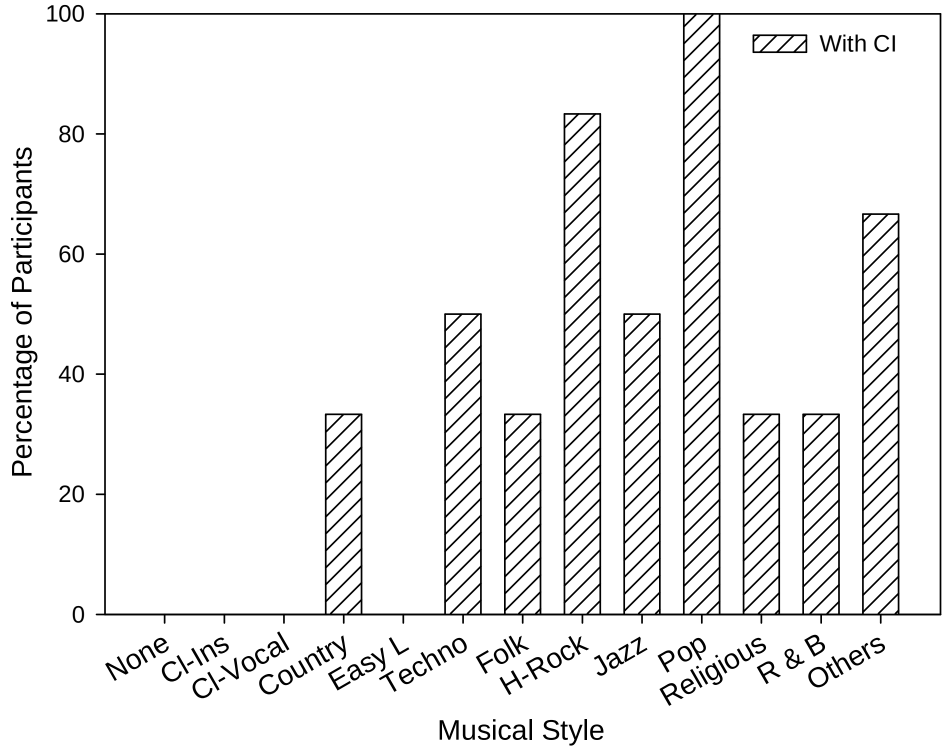

Figure 19. Percentage of CIC participants (after receiving their CI) reporting the different musical styles they listened to.

4.1.2 Formal Music Training Experience

The percentage of participants who were involved in formal music activities after receiving a hearing device are displayed in Figure 20. These types of activities included playing/learning an instrument, singing, theory, music classes at school, music classes at university, and others. The majority of the CIC participants reported that they played/learnt a musical instrument. Fifty-percent (8/16) of the CIA participants reported to have received formal music training before receiving a CI but only 6% reported receiving formal music training after having the implant. Prior to hearing loss, the CIA participants received formal training in piano, recorder, guitar, and flute, as well as in orchestra, band, choir, musical theatre, and other formal music activities. Approximately 60% of the HA participants reportedly received formal training in music (orchestra, band, choir, and musical theatre, and in a variety of musical instruments) prior to receiving HAs. After receiving the HAs, only 10% of the HA participants received formal training and only in the form of a choir. Sixty-six percent (4/6) of CIC participants reportedly received formal training in music with their CI.

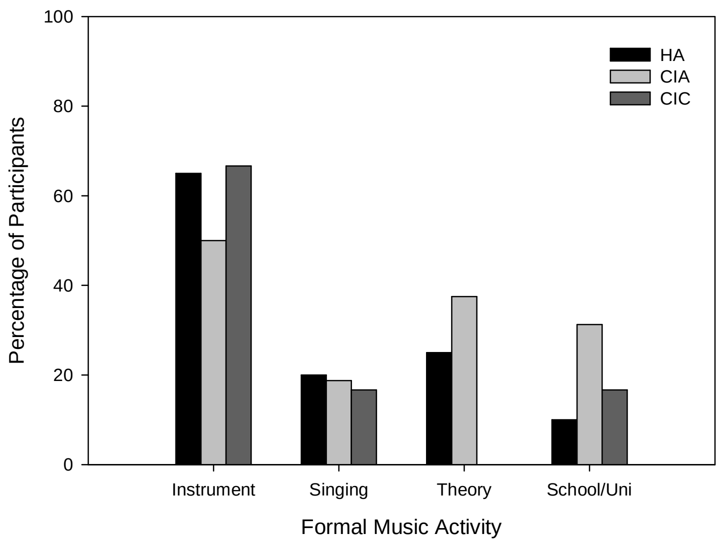

Figure 20. Percentage of the CIA, CIC, and HA participants who engaged in some form of formal music activities after receiving their hearing device.

4.1.3 Informal Music Training Experience

A total of 62% (10/16) of CIA participants reported being involved in some sort of informal music activities before receiving a CI (during childhood and teenage years), while only 6% (1/16) reported having informal training in music after receiving the implant. Before receiving HAs, 15% (3/20) of the participants were involved in playing keyboard, 5% (1/20) in singing, and 5 % (1/20) in playing trumpet. After receiving HAs, the percentage of the participants who played keyboard increased to 25% and the percentage of those playing trumpet remained at 5% (1/20). A total of 50% of the CIC participants attended informal music activities with their CI.

4.1.4 Ease of Performing Pitch-Related Identifications Before Training

Figure 21 illustrates the percentage of participants in each group expressing different levels of ease, on a five-point scale ('never', 'sometimes', 'often', 'very often', and 'always'), for the identification of a variety of listening tasks while wearing their hearing devices. The tasks included identifying male speaker (MSp), male singer (MSin), female speaker (FSp), female singer (FSin), speaker in background noise (Sp-N), singer in background music (Sin-M), individual speaker in a group (In-Sp), individual singer in a group (In-Sin), question/statement (Q/S), familiar melody (FM), and emotion (Emotions). Specific observations made from an inspection of Figure 21 regarding the ease of detecting pitch-related differences in each of the 11 identification tasks are as follows.

1. Male Speaker (Msp): A small percentage of both CIC (16%, 1/6) and CIA (6%, 1/16) participants could 'never' identify a male speaker's voice. More than a quarter of CIA (31%, 5/16), CIC (50%, 3/6), and HA (60%, 12/20) participants could 'very often' identify a male speaker's voice.

2. Male Singer (MSin): A small percentage of CIA participants (6%, 1/16) could 'never' identify a male singer's voice, while all participants of the other two groups could identify a male singer's voice. A moderately high percentage of the CIA (43%, 7/16) and HA (55%, 11/20) participants could 'very often' identify a male singer's voice. None of CIC participants reportedly could 'always' identify a male singer.

3. Female Speaker (FSp): A small percentage (lower than 25%) of both CI groups participants (CIA= 6%, 1/16; CIC= 16%, 1/6) reportedly could 'never' identify a female speaker's voice. Similar to the results obtained for the male speaker's voice, more than one third of the participants in each group could 'very often' identify a female speaker's voice.

4. Female Singer (FSin): One third (33%, 2/6) of the CIC participants and a small percentage of the CIA participants (6%, 1/16) reportedly could 'never' identify a female singer's voice. Similar to the results obtained for a male singer's voice, none of the CIC participants reportedly could 'always' identify a female singer's voice.

5. Speaker from background noise (Sp-N): A low percentage of both CI groups (CIA: 25%, 4/16; CIC: 16 %, 1/6) reported that they could 'never' identify a speaker from the background noise. More than a quarter of the participants in each group could 'often' identify a speaker from background noise.

6. Singer from background music (Sin-M): A low percentage of both HA participants and CI groups (HA = 0%, CIA= 12%, 2/16; CIC = 17%, 1/6) reported that they could 'never' identify a singer from background music.

7. Individual speaker in a group (In-Sp): A small percentage of CIA (25%) and CIC (17%, 1/6) participants reported that they could 'never' identify an individual speaker from a group. An equal percentage (40%, 8/20) of HA participants reported that they could 'sometimes' and 'often' identify an individual speaker in a group.

8. Individual singer in a group (In-Sin): More than one third of the CIA (37%, 6/16) and the CIC participants (50%, 3/6) reported that they could 'never' identify an individual singer in a group of singers. More than one third of the HA participants reportedly could ‘sometimes’ or ‘often’ identify an individual singer in a group. None of the participant groups reported that they could ‘always’ identify an individual singer in a group of singers.

9. Question/Statements (Q/S): A small percentage of the CIC participants (17%, 1/6) reported that they could ‘never’ differentiate between questions and statements. A moderately high percentage of CIA (44%, 7/16) and HA participants (55%, 11/20) reportedly could ‘often’ detect the difference between questions and statements.

10. Familiar Melodies (FM): Across the three participant groups, the HA participants showed the best results in that they reportedly were able to identify the familiar melodies easily The CIC participants (83%, 5/6) reportedly could only ‘sometimes’ identify familiar melodies and the CIA participants (12%, 2/20) reported that they could ‘never’ identify a familiar melody.

11. Emotions: A low percentage of both CI groups (CIA= 19%, 3/16; CIC = 17%, 1/6) reported that they could ‘never’ identify emotions in speech. More than one third of the HA participants (HA = 40%, 8/20) reportedly could ‘often’ identify emotions in speech.

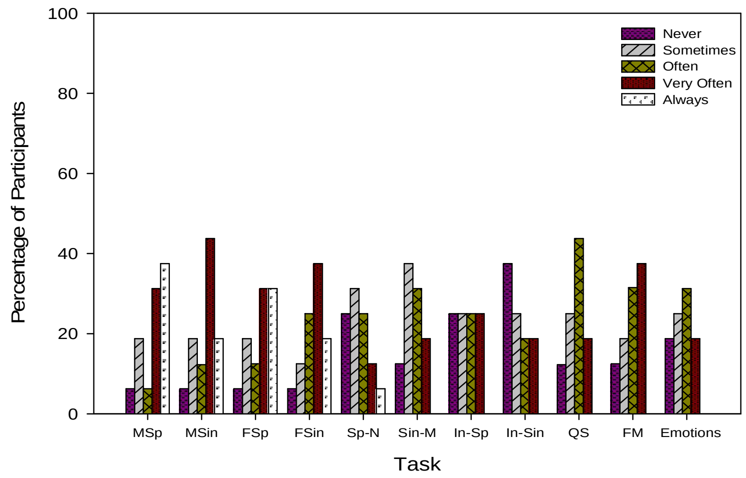

Figure 21a. CIA

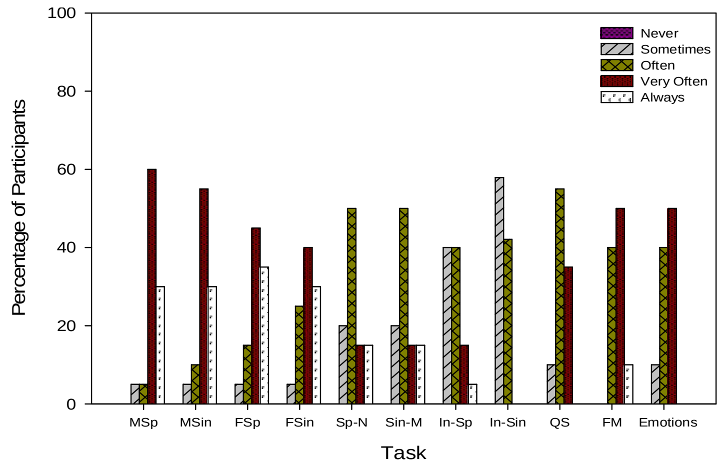

Figure 21b. HA

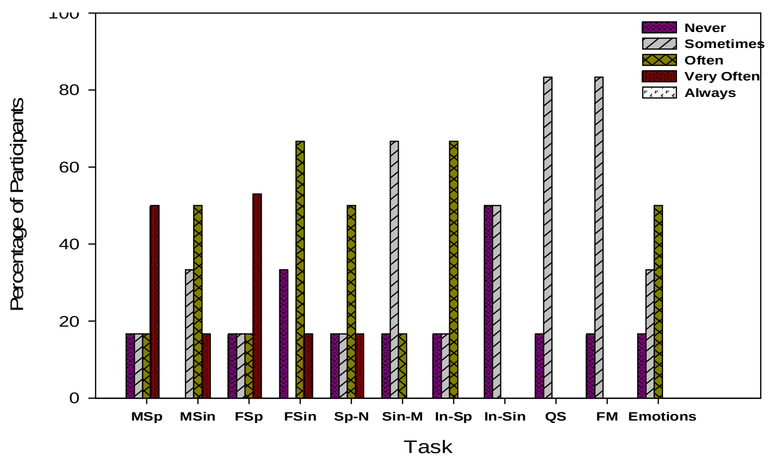

Figure 21c. CIC (as indicated by Parents of the CIC participants)

Figure 21. Percentage of the CIA, CIC, and HA group participants expressing different levels of ease (never, sometimes, often, very often, always) in detecting pitch-related differences in a variety of tasks with their listening devices.

4.1.5 Attendance at Music-Related Activities

The percentage of participants in each group attending different music-related activities at different frequency (none, monthly, weekly, and daily) with their current hearing device are summarized in Figure 22. Specific observations made from an inspection of Figure 22 regarding the attendance frequency for each of the music-related activities are:

1. **Solo singing (Solo):** A high percentage of CIA (88%, 14/16) and HA participants (93%, 19/20) never took part in solo singing after receiving their hearing device. Fifty percent of the CIC participants took part in 'monthly' solo singing activities.

2. **Group singing (Grp):** A high percentage of participants (CIA= 82%, 13/16; HA= 85%, 17/20; CIC= 50%, 3/6) never took part in group singing activities after receiving their hearing device. Furthermore, none of the participants engaged in 'daily' group singing activities.

3. **Musical Theatre (Theatre):** A high percentage (CIA= 88%, 14/16; HA=90%, 18/20; CIC= 100%, 6/6) of participants never attended musical theatre after receiving their implant or HAs.

4. **Play/learn a solo instrument (Play-Ind):** A high percentage of the CIA (93.75%, 15/16) and the HA participants (80%, 16/20) never took part in playing/learning a musical instrument after receiving their CI or HAs.

5. **Play/learn an instrument in a group (Play-Grp):** None of the CIA and HA participants took part in playing/learning a musical instrument in a group after receiving their implant or HAs. The majority of the CIC participants (66%, 4/6) also did not take part in playing or learning an instrument in a group.

6. **Musical concerts (Concerts):** More than 50% of all three participant groups (CIA= 50%, 3/6; HA= 75%, 15/20; CIC= 66%, 4/6) never attended musical concerts after receiving their CI or HAs.

7. Recorded Speech (R-Sp): Fifty-percent (3/6) of the CIC participants listened to recorded speech daily. Approximately18% (3/16) of the CIA and 25% (5/20) of the HA participants 'never' listened to recorded speech.

8. Listening to live or recorded music (R-Music): All of the CIC participants (6/6) listened to live or recorded music 'daily'. Fifty-percent (8/16) of the CIA participants never listened to live or recorded music. Fifty-percent (10/20) of the HA participants listened to live or recorded music 'daily'.

9. Music theory: None of the CIA and HA groups attended music theory classes after receiving their CI or HA. A few CIC participants attended music theory classes 'daily' (33%, 2/6) or 'monthly' (16%, 1/6).

10. Read music magazines: All participants in the CIA and CIC groups and a high percentage (75%, 15/20) of the HA participants reported that they had never read music magazines after receiving their CIs or HAs.

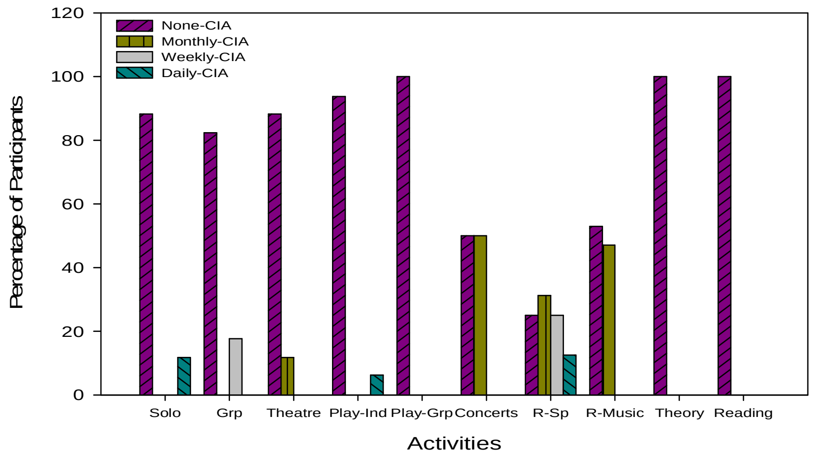

Figure 22a. CIA

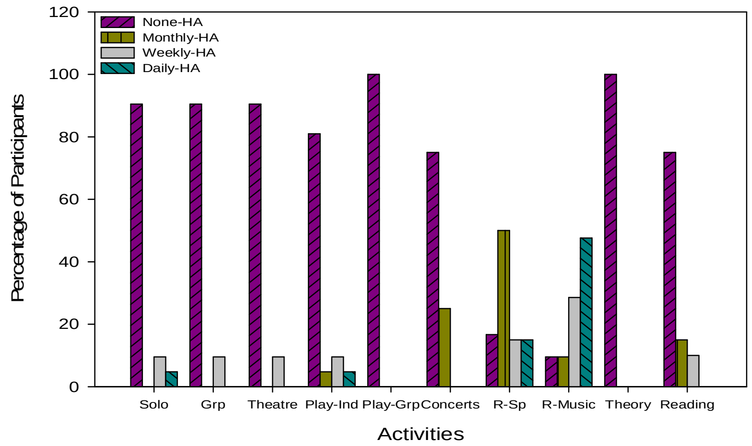

Figure 22b. HA

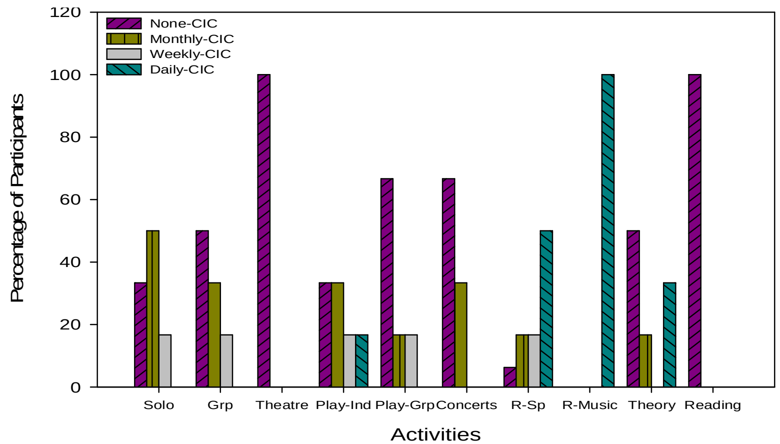

Figure 22c. CIC (as indicated by Parents of the CIC participants)

Figure 22. Percentage of participants in each of the CIC, CIA, and HA groups attending different music-related activities at different frequency (none, monthly, weekly, and daily) with their current hearing device.

When reasons for not taking part in music related activities were investigated, 7/16 CIA participants (37.5%) explained that they do not enjoy listening to music any more, 37.5% mentioned that music sounds unpleasant through the implant, and 25% described that they have stopped taking part in music related activities because they tend to hear two voices through the implant. When participants were asked to describe their experiences of listening to music through a CI, 37.5% mentioned that they have started enjoying listening to music more, 25% mentioned that they continued enjoying listening to music, 12.5% mentioned that they started disliking enjoying listening to music, 12.5% haven't experienced any change in music, and 12.5% indicating other reasons .

According to reports from parents of the CIC participants, 50% (3/6) of the children attended music-related activities at school and on average they spent about 3.3 hours a day on these activities for 1.3 years. It was reported that two CIC participants did not attend any music-related activities at school because they did not have a time allocated for music-related activities in their school timetable. One CIC participant reported that he did not attend any music-related activities at school because there was no music program at the school.

When the CIA participants were asked to describe their experiences of listening to music through a CI, 37% (6/16) reported that they started enjoying listening to music more, 12% (2/16) mentioned that they started to dislike listening to music, and 12% reported no change in their music listening. When the HA participants were asked to describe their experiences of listening to music through HAs, 45% (9/20) stated that they continued enjoying listening to music, 30% (6/20) did not experience any change in their music listening, 5% (1/20) started disliking listening to music, and 20% (4/20) stated other reasons such as music sounds different through HAs. When the CIC participants were asked whether they experienced any changes in the way that music sounded over the years, 70% (14/20) responded ‘yes’. All those who responded ‘yes’ agreed that music sounded better through their implant over the years.

4.1.6 Summary of Pre-Training Questionnaire Results

The main findings of this pre-training musical background questionnaire are:

1. Personal interest levels for the CIA and HA participants are higher than their current level of interest in music. Reversed results are observed for the CIC participants.

2. The majority of the CIA and CIC participants listened to musical styles with a strong rhythm with their CIs. In contrast, the majority of the HA participants listened to classical instrumental music.

3. The majority of the CIC participants were found to take part in formal and informal music activities.

4. The percentage of the CIA participants who took part in formal and informal activities decreased after receiving their CI.

5. The CIC participants reported that they could not ‘always’ identify all of the pitch-related tasks.

6. None of the hearing impaired groups reported to be able to ‘always’ identify a ‘singer in a group’ or perceive a question/statement distinction.

7. A small percentage of the CIA participants could not identify all of the pitch-related tasks.

8. The majority of the participants in each of the groups never learned or played an instrument in a group, read music magazines, or attended group singing, musical theatre, musical concerts, or music theory classes.

4.2 Objective Tests of Speech and Music Perception

This section contains results from the pre-training test taken at Time one and Time two (post-training or after a waiting period) by the three hearing impaired groups (HA, CIA, and CIC) and the two normal control groups (NHA and NHC).

4.2.1 Pre-Training Test Results For All Participant Groups

The pre-training test scores obtained from the objective tests taken by three hearing impaired groups, namely, HA (n = 20), CIA (n = 16), and CIC (n = 6), and the two normal control groups, NHA (n = 19) and NHC (n = 12), were compared. The means and standard errors of the raw scores for all five participant groups are summarized in Table 4. For the purpose of this study, comparisons were made only between CIA, NHA, and HA groups and between NHC and CIC groups. Results from the MANOVA conducted on the baseline measures in all of the auditory-perceptual tests included in this study for all of the participant groups revealed a significant participant group effect [Pillai's Trace = 2.392, $F(52, 236) = 6.752$, $p < 0.001$, $\eta_p^2 = 0.6$]. The follow-up univariate ANOVA results revealed that all of the 13 test measures showed a significant group effect, with CNC-W exhibiting the largest effect size ($\eta_p^2 = 0.91$), followed in order by CNC-Ph ($\eta_p^2 = 0.85$), CUNY ($\eta_p^2 = 0.82$), FMI-Rh ($\eta_p^2 = 0.75$), EI-Both ($\eta_p^2 = 0.74$), EI-Female ($\eta_p^2 = 0.68$), EI-Male ($\eta_p^2 = 0.66$), FMI-NoRh ($\eta_p^2 = 0.56$), Q/S-Both ($\eta_p^2 = 0.558$), Q/S-Female ($\eta_p^2 = 0.55$), Q/S-Male ($\eta_p^2 = 0.45$), InsI ($\eta_p^2 = 0.44$), and PitchD ($\eta_p^2 = 0.29$).

Table 4. Means and standard errors (SE, in parentheses) of the percent-correct scores obtained by each of the five participants groups (CIA, CIC, HA, NHA, and NHC) for 13 pre-training tests.

Participant Group	Number of participants	CNC-Word	CNC-Phoneme	CUNY Sentence	EI-Male	EI-Female	EI-Both	Q/S-Male	Q/S-Female	Q/S-Both	FMI-Rh	FMI-NoRh	InsI	PR
CIA	16	14.50 (13.30)	24.62 (18.70)	26.23 (19.95)	38.54 (14.55)	41.14 (16.52)	40.07 (12.23)	58.33 (18.76)	60.93 (18.18)	59.82 (14.87)	84.38 (15.38)	46.88 (26.26)	54.80 (17.85)	72.13 (15.34)
CIC	6	21.33 (11.50)	31.37 (11.36)	29.12 (13.32)	41.66 (14.91)	34.72 (14.35)	38.19 (11.00)	41.66 (16.67)	63.89 (8.61)	52.78 (11.08)	38.33 (19.41)	15.00 (8.37)	64.38 12.36)	71.52 (17.57)
HA	20	48.40 (15.68)	63.85 (16.50)	74.56 (20.95)	42.15 (17.09)	55.27 (15.55)	48.55 (13.99)	75.88 (19.29)	81.66 (9.97)	77.91 (13.79)	96.50 (7.45)	80.50 (21.14)	72.34 (13.25)	84.79 (17.73)
NHA	19	96.84 (2.52)	98.26 (1.66)	99.47 (1.17)	78.96 (12.19)	82.01 (9.73)	80.69 (9.22)	89.04 (12.24)	91.23 (9.81)	90.35 (9.43)	99.47 (2.29)	83.68 (17.07)	82.67 (15.19)	89.69 (10.05)
NHC	12	93.67 (4.96)	95.94 (2.79)	98.75 (1.60)	83.84 (14.12)	81.94 (5.98)	82.21 (9.45)	82.64 (13.97)	92.36 (8.30)	87.47 (10.02)	100.00 (0.00)	87.50 (18.15)	90.47 (11.03)	95.48 (4.52)

(1) CUNY Sentence and CNC-Phoneme and Word Identification Tests

For all three speech-in-noise tests (i.e., CUNY, CNC-Phoneme, and CNC-Word), as shown in Figure 23, post-hoc pairwise comparisons using the Dunnett T3 test showed that the NHA group scored significantly higher than the HA and CIA group, the NHC group scored significantly higher than the CIC group, and the HA group scored significantly higher than the CIA group ($p < 0.05$).

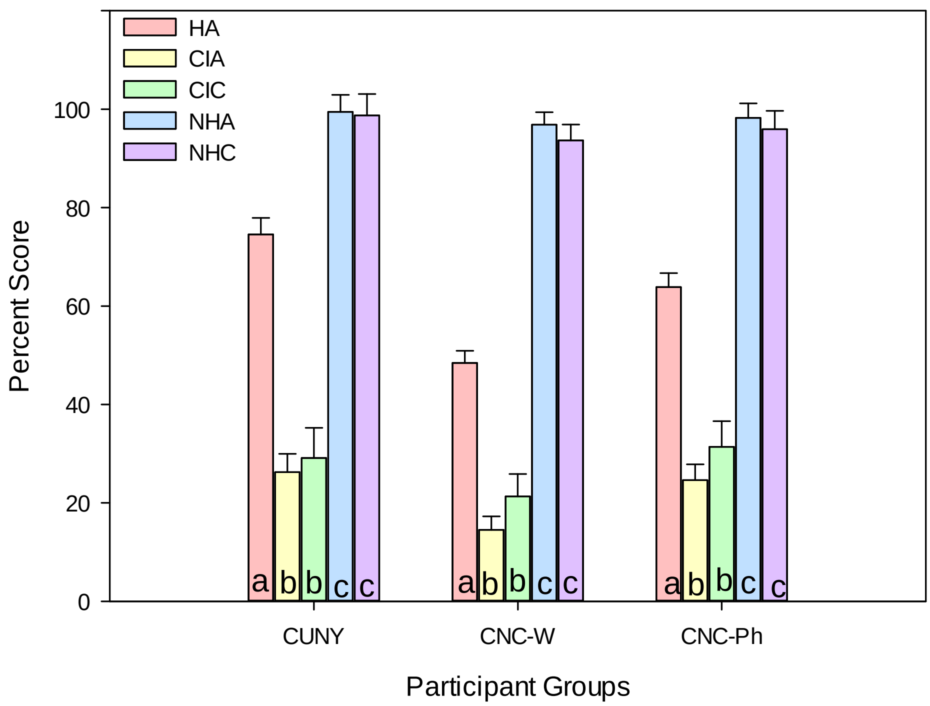

Figure 23. Means and standard errors (in error bars) of the scores from the CUNY-sentence, CNC-word, and CNC-phoneme tests for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are significantly different at the 0.05 level are marked with different letters.

(2) Emotion Identification Tests (EI-Male, EI-Female & EI-Both)

For the EI-Male, EI-Female, and EI-Both tests, as shown in Figure 24, post-hoc pairwise comparisons using the Dunnett T3 test indicated that NHA group scored significantly higher than the HA and CIA groups and the NHC group significantly higher than the CIC group ($p < 0.05$).

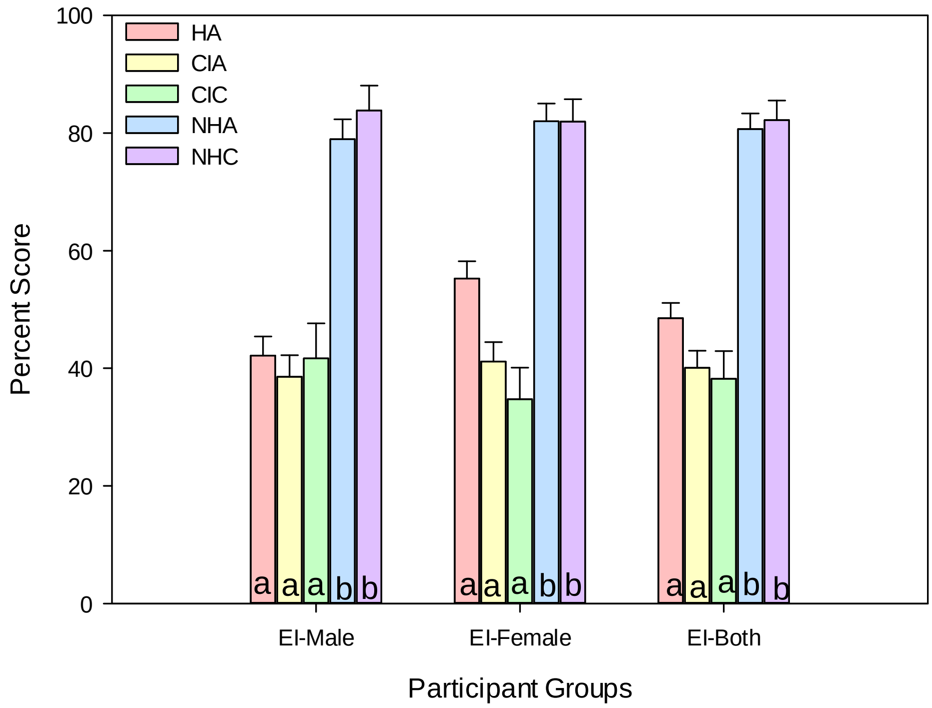

Figure 24. Means and standard errors (in error bars) of the scores from the 'EI-Male', 'EI-Female', and 'EI-Both' tests for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are significantly different at the 0.05 level are marked with different letters.

(3) Question/Statement Identification Tests (Q/S-Male, Q/S-Female, & Q/S-Both)

For all three Q/S tests, no significant difference was observed between the HA and NHA groups. As shown in Figure 25, the HA group scored significantly better than the CIA group for the EI-Male ($p = 0.024$), EI-Female ($p = 0.005$), and EI-Both ($p = 0.007$) tests. The NHC scored significantly better than the CIC group for the EI-Male ($p = 0.006$), EI-Female ($p = 0.001$), and EI-Both tests ($p = 0.001$).

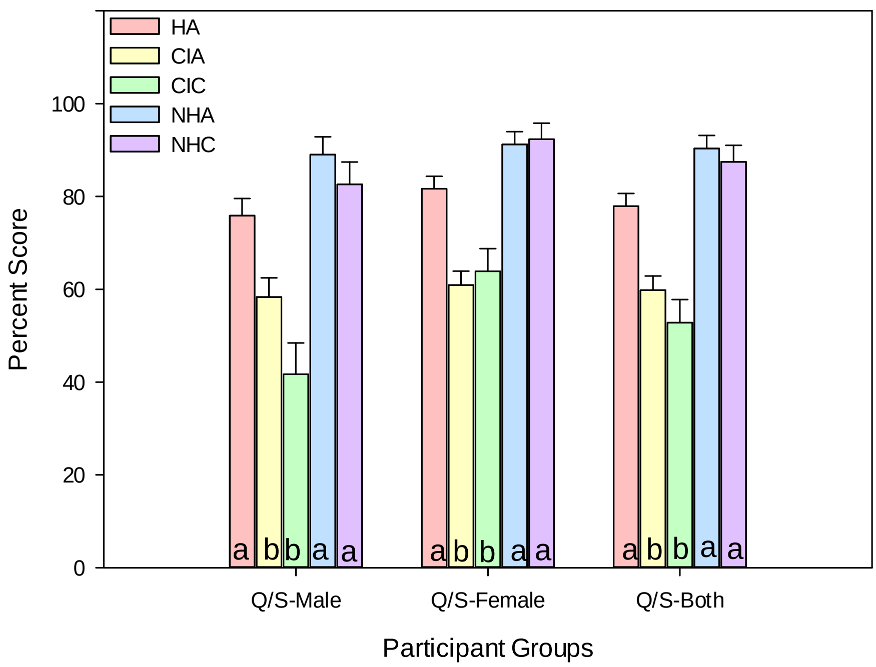

Figure 25. Means and standard errors (in error bars) of the scores from the Q/S-Male, Q/S-Female, and Q/S-Both tests for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are significantly different at the 0.05 level are marked with different letters.

(4) Familiar Melody Identification Tests (FMI-Rh & FMI-NoRh)

For both FMI-Rh and FMI-NoRh tests, no significant difference on the test scores was found between NHA and HA groups. The NHC group performed significantly better than the CIC group for the FMI-Rh ($p = 0.004$) and FMI-NoRh ($p = 0.001$) tests. The NHA group also scored significantly better than the CIA group for the FMI-Rh ($p = 0.013$) and FMI-NoRh ($p = 0.001$) tests. In addition, the HA group was found to perform significantly better than the CIA group in the FMI-NoRh test ($p = 0.003$) but no significant difference between these two groups was found in the FMI-Rh test (see Figure 26).

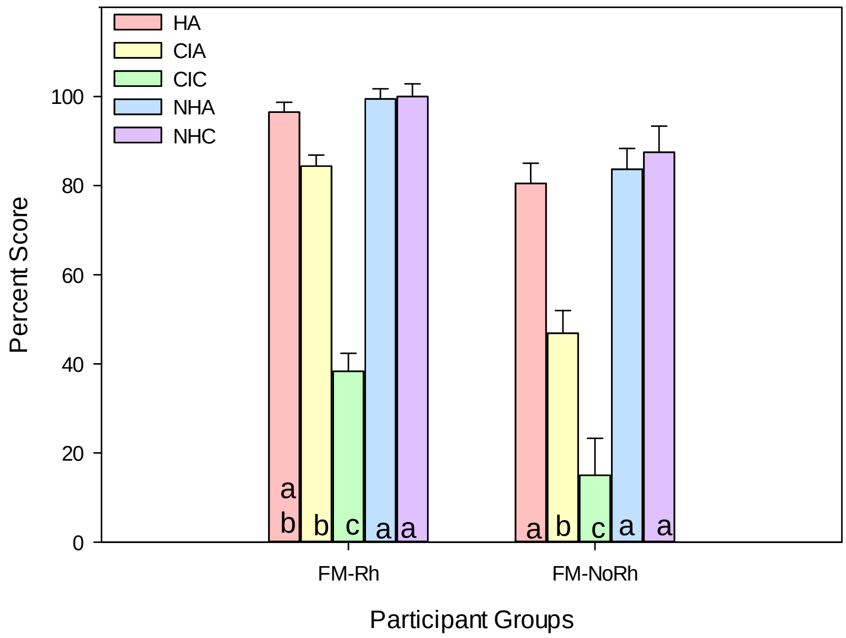

Figure 26. Means and standard errors (in error bars) of the scores from the FMI-Rh and FMI-NoRh tests for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are not significantly different are marked with the same letters.

(5) Familiar Musical Instrument Identification Test (InsI)

For the InsI test, post-hoc pairwise comparisons using Dunnett T3 test revealed no significant difference between HA and NHA groups. As shown in Figure 27, the CIA group scored significantly lower than both NHA ($p < 0.0001$) and HA ($p = 0.028$) groups. The CIC group showed significantly lower scores than the NHC group ($p = 0.015$).

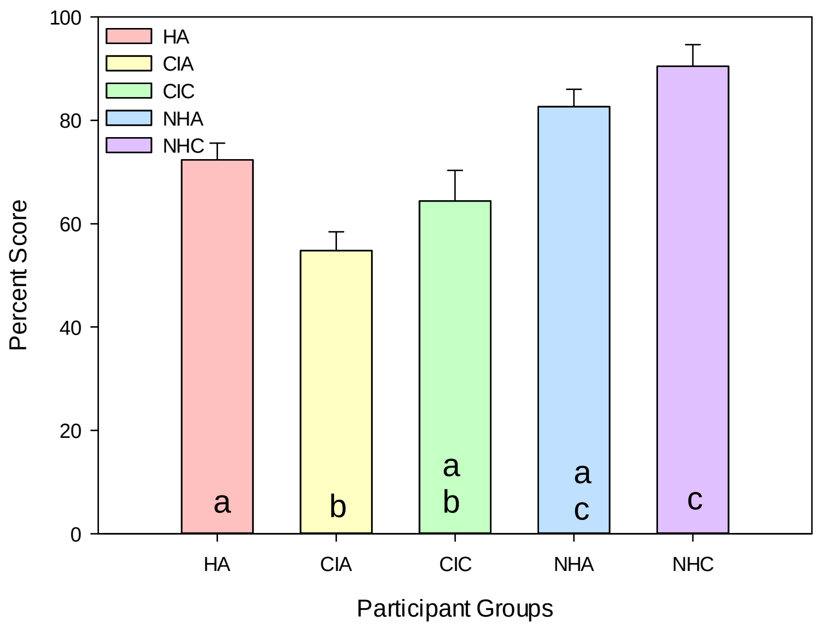

Figure 27. Means and standard errors (in error bars) of the scores from the InsI test for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are significantly different at the 0.05 level are marked with different letters.

(6) *Pitch Ranking (PR) Test*

For the PR test, no significant difference in the average performance across all 12 semitone levels was found between the CIA and HA groups or between the HA and NHA groups. As shown in Figure 28, the CIA group scored significantly poorer than the NHA group ($p = 0.003$) and the CIC group scored significantly poorer than the NHC group ($p = 0.008$). Results of a follow-up analysis of the PR test scores at individual semitone separation levels were shown in Appendix 14.

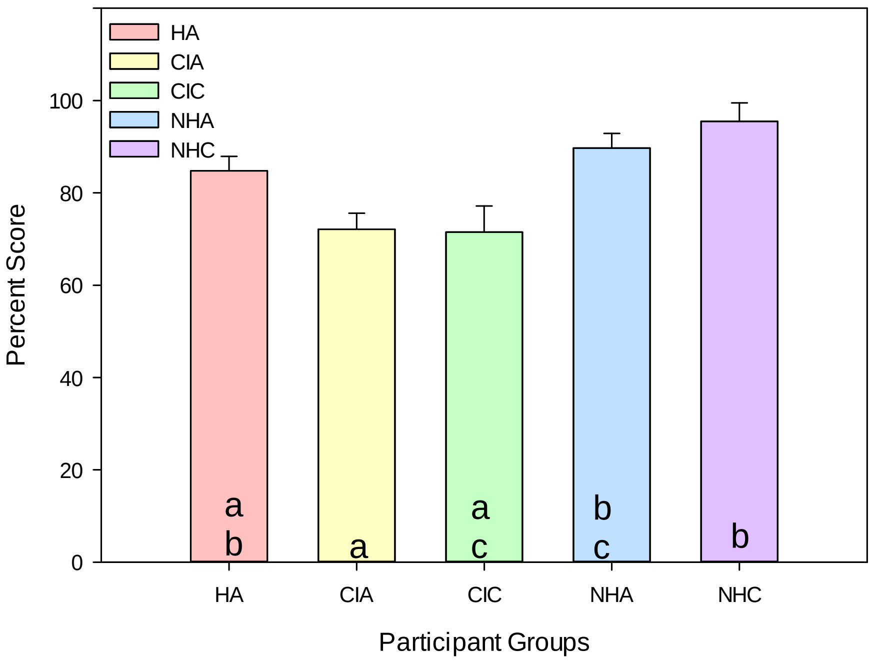

Figure 28. Means and standard errors (in error bars) of the scores from the PR test for the HA, CIA, CIC, NHA, and NHC groups, respectively. The groups that are significantly different at the 0.05 level are marked with different letters.

Summary of the Pre-Training Test Results

- Both NH groups obtained the highest score for all of the pre-training tests. The HA participants did not significantly differ from the NH groups in the test scores for FMI-Rh, FMI-NoRh, PR, and all three Q/S tests.
- The HA group performed significantly better than both CI groups in all the pre-training tests except for the PR and all three EI tests.

4.2.2 Comparisons between Pre- and Post-Training Scores for V1T

A series of planned comparison *t*-tests were performed on the pre- and post-training test scores obtained during the V1T period of the experiment. The results for each of the participant groups, for each of the objective measures of speech and music perception are reported below. In order to compare the improvement in performance across the training and hearing impaired control groups, a ‘difference’ score was also calculated (i.e., the difference between the pre- and post-training test scores). An average difference score was determined for each training group and subsequently compared with that of the hearing impaired control groups using a series of paired sample t-tests. The means and standard errors of the percent-correct scores for the eight participant groups are shown in Table 5 for all 13 pre-training tests (i.e., tests before the V1T period) and in Table 6 for the post-training tests (i.e., tests after the V1T period). A summary of the test outcomes for the three participant groups trained with V2T is shown in Table 7 for the pre-training (i.e., before training with V2T) and in Table 8 for the post-training tests (i.e., after training with V2T.

Table 5. Means and standard errors (SE, in parentheses) of the percent-correct scores for all eight participants groups for the 13 pre- training tests (i.e., tests before the V1T period).

Participant Group	CNC-Word	CNC-Phoneme	CUNY Sentence	EI-Male	EI-Female	EI-Both	Q/S-Male	Q/S-Female	Q/S-Both	FMI-Rh	FMI-NoRh	InsI	PR
HA-T1	52.40 (4.59)	66.30 (3.61)	79.74 (5.84)	39.15 (5.56)	57.22 (5.60)	47.47 (4.73)	82.49 (5.18)	82.49 (2.90)	73.30 (5.05)	99.00 (1.000	90.00 (5.16)	72.54 (4.21)	83.75 (7.33)
HA-C	44.40 (5.21)	61.39 (6.59)	69.38 (7.24)	45.82 (5.99)	53.31 (4.33)	49.61 (4.31)	69.25 (6.47)	83.80 (3.52)	73.33 (5.04)	94.00 (3.05)	71.00 (6.90)	72.14 (4.39)	83.41 (3.58)
CIA-T1	15.00 (4.82)	24.64 (7.04)	30.69 (8.07)	39.58 (4.38)	40.62 (7.62)	40.04 (4.95)	54.16 (6.86)	62.49 (5.44)	58.33 (5.04)	83.75 (6.52)	42.50 (9.01)	57.00 (6.90)	71.87 (5.02)
CIA-C	14.00 (4.89)	24.57 (6.63)	21.76 (5.98)	37.49 (6.09)	41.66 (3.85)	40.10 (3.93)	62.49 (6.49)	59.37 (7.62)	61.31 (5.76)	85.00 (4.62)	52.25 (9.89)	52.60 (6.02)	72.91 (5.99)
CIC-T1	21.33 (8.74)	34.22 (7.75)	25.98 (2.89)	43.05 (6.05)	38.33 (2.77)	43.05 (6.05)	36.10 (12.10)	61.66 (5.53)	48.61 (8.77)	53.33 (8.81)	53.33 (8.81)	59.00 (9.45)	66.66 (14.43)
CIC-C	21.33 (5.81)	28.51 (6.56)	32.25 (11.38)	33.33 (6.36)	30.53 (12.10)	33.30 (6.36)	47.22 (7.34)	66.63 (4.81)	56.94 (3.67)	23.33 (3.33)	23.33 (3.33)	69.66 (3.17)	76.36 (5.00)
NHA-C	96.84 (0.57)	98.22 (0.52)	99.47 (0.26)	78.96 (2.79)	82.01 (2.23)	80.69 (2.11)	89.03 (2.85)	91.22 (2.25)	90.35 (2.16)	97.47 (0.52)	83.68 (3.91)	82.66 (3.48)	89.69 (2.30)
NHC-C	93.66 (1.43)	95.44 (0.85)	99.75 (0.46)	83.83 (4.07)	81.94 (1.72)	82.21 (2.72)	82.63 (4.03)	92.36 (2.39)	87.46 (2.89)	100.00 (0.00)	87.50 (5.24)	90.46 (3.18)	95.48 (1.30)

Table 6. Means and standard errors (SE, in parentheses) of the percent-correct scores for all eight participants groups for the 13 post- training tests (i.e., tests after the V1T period).

Participant Group	CNC-Word	CNC-Phoneme	CUNY Sentence	EI-Male	EI-Female	EI-Both	Q/S-Male	Q/S-Female	Q/S-Both	FMI-Rh	FMI-NoRh	InsI	PR
HA-T1	61.20 (4.62)	80.43 (3.38)	86.48 (3.91)	72.50 (4.31)	73.74 (4.97)	74.16 (3.55)	88.33 (3.96)	88.33 (4.51)	74.99 (3.82)	100.00 (0.00)	85.00 (5.62)	85.05 (3.39)	94.58 (2.24)
HA-C	44.60 (5.48)	62.66 (6.72)	70.39 (7.40)	58.33 (3.92)	50.83 (6.14)	54.58 (4.90)	75.00 (3.51)	76.66 (4.77)	74.99 (3.82)	97.00 (1.52)	71.00 (3.78)	73.63 (3.62)	83.74 (3.48)
CIA-T1	16.00 (5.23)	29.45 (7.85)	37.07 (8.56)	49.99 (4.98)	47.91 (6.44)	48.99 (5.03)	70.83 (5.45)	69.79 (6.08)	70.31 (5.42)	87.50 (5.59)	46.25 (9.62)	79.15 (7.94)	72.91 (5.89)
CIA-C	16.50 (5.20)	27.91 (6.87)	22.80 (7.30)	50.00 (5.22)	38.54 (5.66)	44.26 (3.04)	62.49 (6.29)	61.45 (5.44)	61.45 (5.02)	88.75 (6.10)	48.75 (13.68)	47.56 (7.49)	65.62 (7.78)
CIC-T1	26.67 (3.52)	53.33 (3.35)	25.94 (3.29)	52.77 (9.10)	41.66 (12.73)	52.77 (9.10)	63.88 (15.46)	58.38 (12.72)	61.11 (13.24)	40.00 (10.00)	40.00 (10.00)	62.88 (1.97)	68.05 (13.89)
CIC-C	17.33 (6.66)	28.44 (8.85)	33.86 (9.39)	45.83 (0.00)	47.22 (2.77)	45.83 (0.00)	63.88 (12.10)	47.22 (7.34)	54.16 (8.67)	23.33 (8.81)	23.33 (8.81)	75.23 (18.09)	79.16 (2.40)
NHA-C	95.36 (0.80)	97.95 (0.41)	99.52 (0.14)	82.45 (2.61)	85.94 (2.38)	83.97 (2.06)	91.66 (2.38)	90.35 (3.26)	90.97 (2.55)	97.47 (0.52)	79.47 (4.42)	87.15 (3.85)	88.59 (1.76)
NHC-C	93.00 (1.21)	96.60 (0.48)	97.92 (0.90)	86.80 (2.16)	86.80 (2.39)	87.48 (2.45)	93.75 (1.49)	88.88 (4.95)	90.87 (2.96)	98.33 (1.67)	85.00 (6.33)	90.26 (2.12)	97.22 (1.18)

Table 7. Means and the standard errors (SE, in parentheses) of the percent-correct scores for the three participant groups trained with V2T for the 13 pre-training tests (i.e. Post-training test 1).

Participant Group	CNC-Word	CNC-Phoneme	CUNY Sentence	EI-Male	EI-Female	EI-Both	Q/S-Male	Q/S-Female	Q/S-Both	FMI-Rh	FMI-NoRh	InsI	PR
HA-T2	39.14 (6.84)	56.62 (8.75)	66.83 (10.10)	58.33 (4.81)	44.99 (7.27)	49.99 (7.27)	75.00 (3.66)	79.76 (3.57)	76.18 (3.11)	97.14 (1.84)	71.42 (5.08)	72.42 (5.06)	85.11 (4.44)
CIA-T2	16.50 (5.20)	27.91 (6.78)	22.85 (7.30)	50.00 (5.22)	38.54 (5.66)	44.26 (3.04)	62.49 (6.29)	59.37 (5.08)	61.45 (5.02)	88.75 (6.10)	48.75 (13.68)	47.56 (7.49)	72.93 (6.14)
CIC-T2	14.00 (10.00)	20.66 (7.33)	34.00 (16.20)	45.83 (4.16)	45.83 (0.00)	45.83 (0.00)	74.99 (8.33)	54.16 (4.16)	62.50 (4.17)	40.00 (10.00)	15.00 (5.00)	62.85) (22.50)	79.16 (4.16)

Table 8. Means and the standard errors (SE, in parentheses) of the percent-correct scores for the three participant groups trained with V2T for the 13 post-training tests (i.e., post-training test 2).

Participant Group	CNC-Word	CNC-Phoneme	CUNY Sentence	EI-Male	EI-Female	EI-Both	Q/S-Male	Q/S-Female	Q/S-Both	FMI-Rh	FMI-NoRh	InsI	PR
HA-T2	41.71 (8.13)	55.04 (5.27)	74.36 (10.10)	63.09 (4.00)	63.01 (5.99)	63.09 (4.84)	92.85 (2.17)	88.09 (4.40)	89.28 (2.70)	100.00 (0.00)	85.71 (5.28)	90.59 (4.99)	96.42 (1.91)
CIA-T2	14.00 (3.73)	27.83 (5.27)	27.81 (8.29)	54.16 (3.85)	50.00 (5.22)	50.00 (4.45)	66.66 (6.49)	75.00 (6.10)	70.83 (3.87)	91.25 (3.98)	78.75 (9.14)	68.71 (6.26)	80.72 (5.94)
CIC-T2	20.00 (0.00)	26.46 (4.20)	34.31 (0.00)	45.83 (4.17)	62.50 (4.17)	54.16 (4.16)	70.83 (4.16)	66.67 (0.00)	77.08 (2.08)	55.55 (5.00)	35.00 (15.00)	82.50 (7.50)	79.16 (4.16)

(1) CUNY Sentence and CNC-Word and CNC-Phoneme Identification Tests

Results showed no significant improvement following the V1T period for the CUNY Sentence and CNC-Word identification test scores for any of the eight participant groups. Results from a series of t-tests conducted to compare the control and V1T groups on the pre-and-post difference scores also failed to reveal a significant training effect on the CUNY sentence and CNC-word tests.

As shown in Figure 29, for the CNC-phoneme test, the post-training scores were significantly better than the pre-training scores for both HA-T1 [t(9) = -4.127, p = 0.003] and CIC-T1 groups [t(2) = -4.118, p = 0.054]. No significant difference was observed between training and control groups for the pre-and-post difference scores.

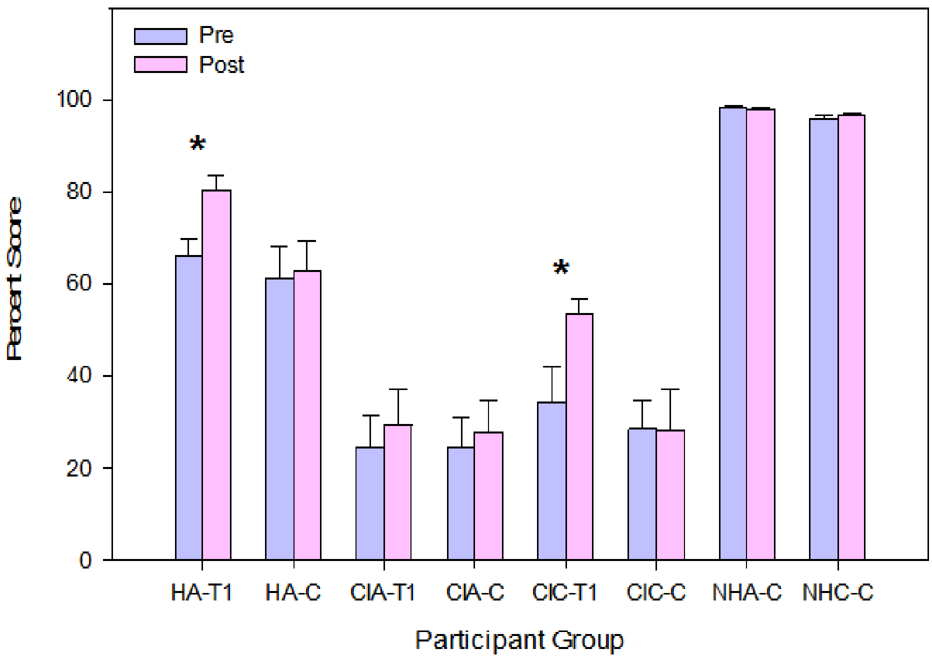

Figure 29. Means and standard errors (in error bars) for the pre- and post-training CNC-Ph test scores in each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

(2) Emotion Identification Tests (EI-Male, EI-Female & EI-Both)

The mean EI-Male scores obtained during the pre- and post-V1T testing sessions for each of the eight participant groups are displayed in Figure 30. Across all the participant groups, the mean post-training scores were higher than the pre-training scores. However, results from a series of paired t-tests conducted on these measures revealed a significant session effect only for the HA-T1 [$t(9) = -6.331$, $p < 0.001$] and HA-C [$t(9) = -3.01$, $p = 0.015$] groups. Results from the t-tests conducted on the pre-and-post difference scores also showed that the HA-T1 (34.02%) had a significantly greater improvement than the HA-C group [$t(18) = 3.16$, $p = 0.005$].

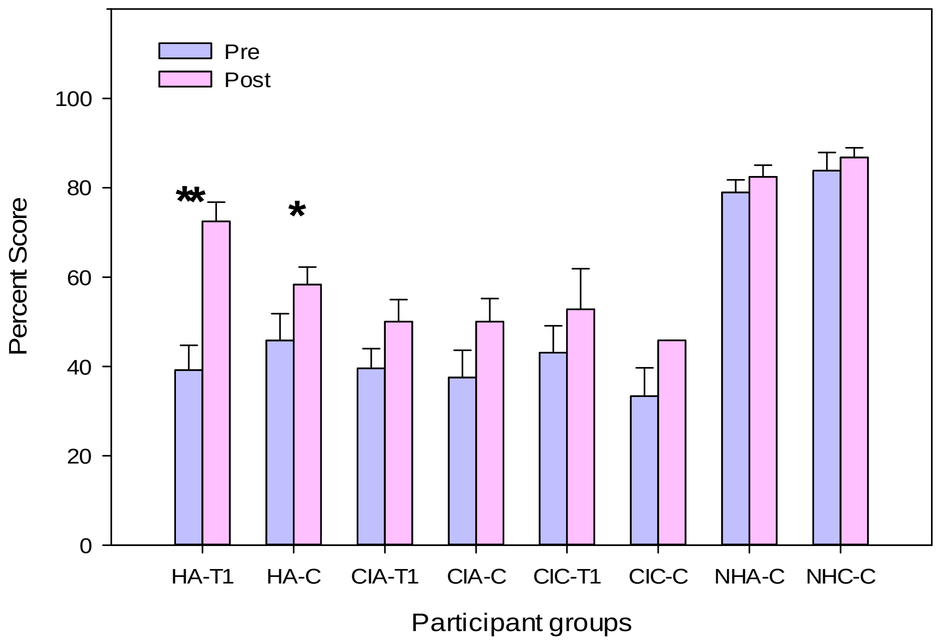

Figure 30. Means and standard errors (in error bars) for the pre- and post-training 'EI-Male' scores in each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level. '**' indicates the difference between the paired groups is significant at 0.001 level.

Results for the pre- and post-training EI-female scores obtained during the V1T period are shown in Figure 31. A statistically significant improvement was found for the HA-T1 [t(9) = -2.46, p = 0.03] and NHC-C [t(11) = -2.55, p = 0.02] groups. Results from t-tests conducted on the pre-and-post difference scores revealed that the HA-T1 group (16.52%) had a significantly greater improvement [t(18) = 2.511, p = 0.022] than the HA-C group. None of the other participant groups showed a significant change in performance after the V1T period.

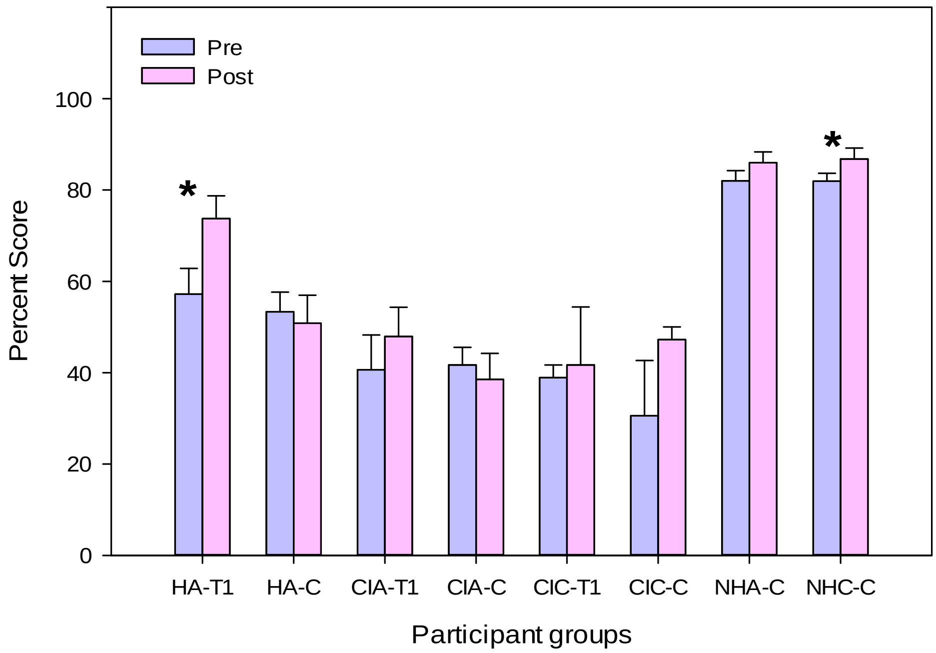

Figure 31. Means and standard errors (in error bars) for the pre- and post-training 'EI-Female' test scores in each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

The pre- and post-training EI-Both test scores obtained during the V1T period for each of the participant groups are shown in Figure 32. A statistically significant improvement was found for the HA-T1 group [$t(9) = -5.40$, $p < 0.001$], CIA-T1 group [$t(7) = -3.89$, $p < 0.01$], and NHC-C group [$t(11) = -2.28$, $p = 0.04$] . Examination of the pre-and-post difference scores indicated that the HA-T1 group (26.69%) showed a greater pre-and-post difference score [$t(18) = 4.01$, $p < 0.001$] than the HA-C group (4.97%).

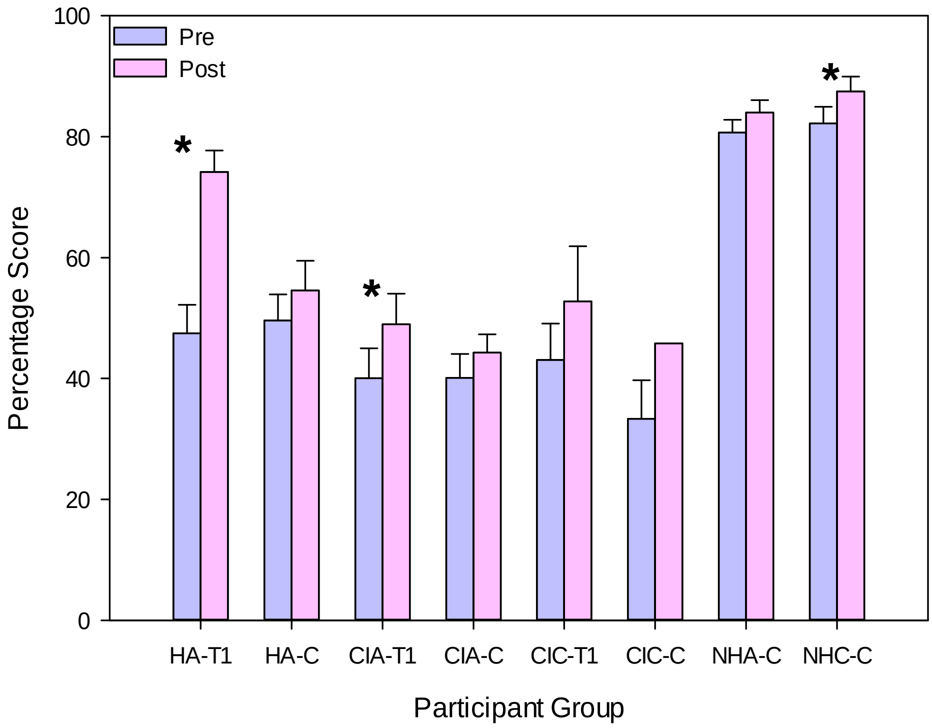

Figure 32. Means and standard errors (in error bars) for the pre- and post-training EI-Both test scores in each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

(3) Question/Statement Identification Tests (Q/S-Male, Q/S-Female, & Q/S-Both)

The pre- and post-V1T period Q/S-Male scores for each participant group are shown in Figure 33. The only participant group that showed a significant post-V1T period change in the Q/S-Male test was the NHC-C group [t(11) = -3.85, p = .01]. None of the participant groups exhibited a significant post-V1T period change in performance for the Q/S Female or Q/S-Both test scores. In addition, results from the analysis of the pre-and-post difference scores failed to differentiate between the eight participant groups in any of the question/statement identification tests.

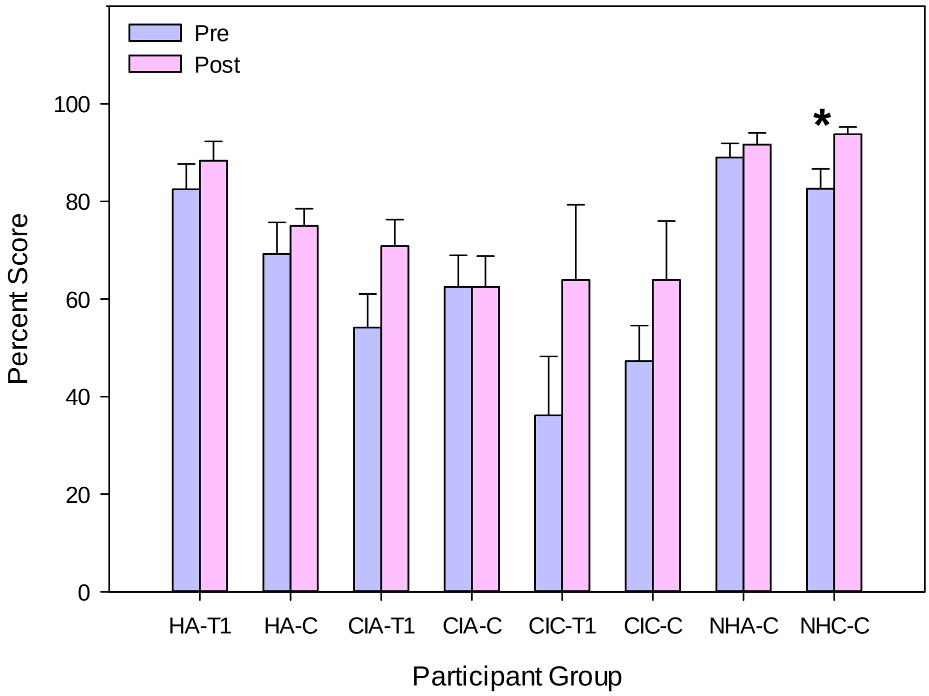

Figure 33. Means and standard errors (in error bars) for pre- and post-training period Q/S-Male scores for each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

(4) Familiar Melody Identification Tests (FMI-Rh & FMI-NoRh)

No significant difference was found between the pre- and post-V1T period scores in any of the eight participant groups for the FMI-Rh test as well as for the FMI-NoRh test. Likewise, no significant group difference was found when comparing the pre-and-post difference scores. In addition, female HA-T1 participants were found to score significantly better than male HA-T1 participants in the post-training FMI-NoRh test.

(5) Familiar Musical Instrument Identification Test (InsI)

For the InsI test, a significant change in performance was only found for the CIA-T1 group [t(7) = -3.456, p = 0.01], showing an improvement of 22.15% after V1T (see Figure 34). Analysis of the difference scores yielded non-significant results.

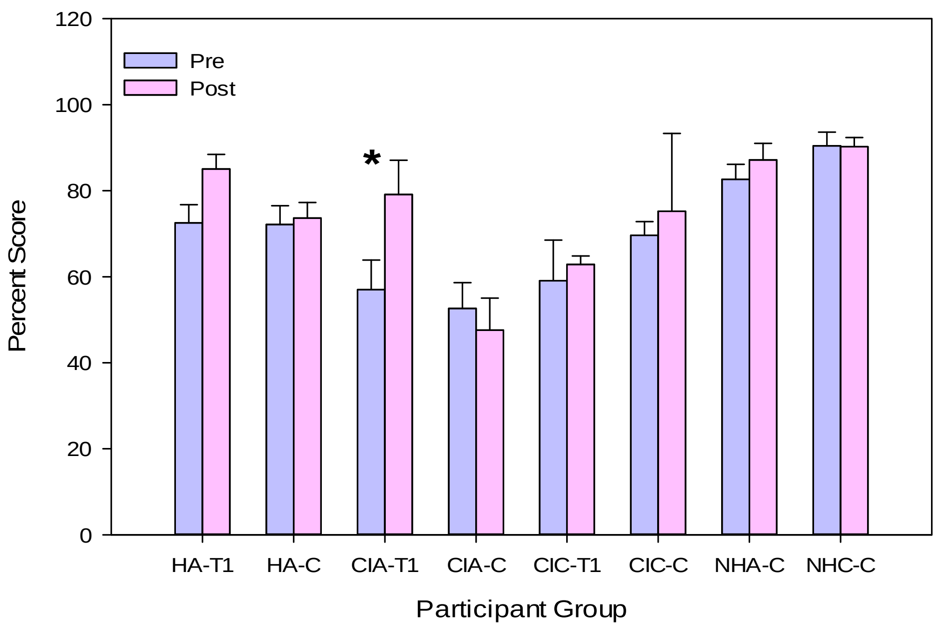

Figure 34. Means and standard errors (in error bars) for pre- and post-V1T period InsI test scores for each of the eight participant groups. ‘*’ indicates the difference between the paired groups is significant at 0.05 level.

(6) Pitch Ranking Test (PR)

For the PR test scores, the only participant group showing a significant change following the V1T period was the CIA-C group [$t(7) = 2.49$, $p = 0.04$] (see Figure 35). Analysis of the pre-and-post difference scores also revealed no significant difference between the training and control groups. Therefore, the reduction in the test scores in the CIA-C group can be considered a trivial artefact effect.

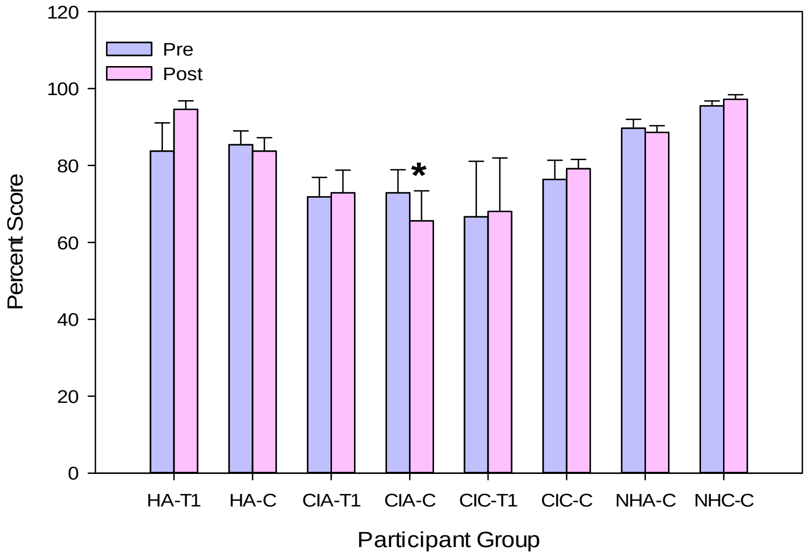

Figure 35. Means and standard errors (in error bars) for pre- and post-V1T period PR test scores for each of the eight participant groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

4.2.3 Comparisons between Pre- and Post-Training Scores for V2T

Results from a series of paired t-tests conducted on the post-training scores achieved by the participants involved in V2T (HA-C-T2: n = 7; CIA-C-T2: n = 8; CIC-C-T2: n = 2) are reported as follows.

(1) CUNY Sentence and CNC-Phoneme and Word and Phoneme Identification Tests

Results from a series of paired t-tests conducted on the pre- and post-training scores in the three hearing impaired groups trained with V2T did not show a significant training effect for any of the tests. Furthermore, analysis of the difference scores yielded non-significant results.

(2) Emotion Identification Tests (EI-Male, EI-Female & EI-Both)

Paired t-test results for the pre- and post-training EI-Male test scores failed to show a significant training effect for any of the participant groups. For the EI-Female test scores, a significant training effect was found for both HA-T2 [$t(6) = -3.66$, $p = 0.01$] and CIA-T2 [$t(7) = -3.27$, $p = 0.01$] groups (see Figure 36).

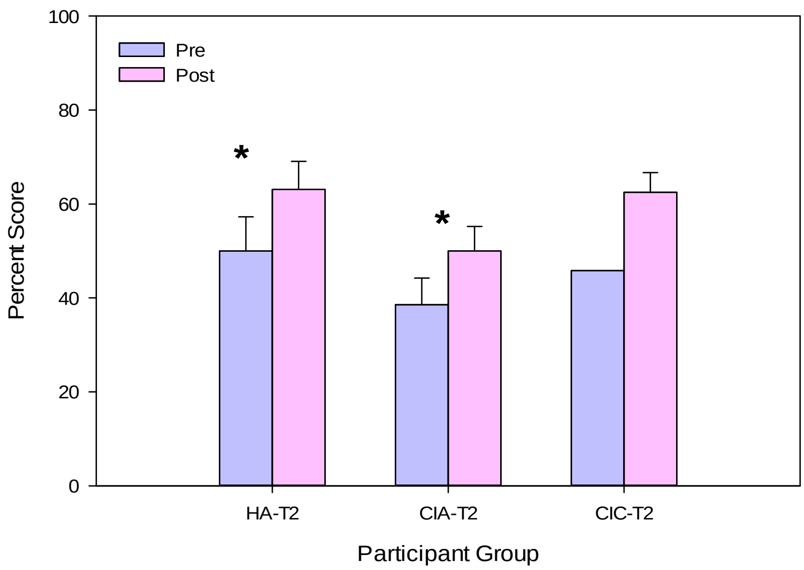

Figure 36. Means and standard errors (in error bars) for the pre- and post-training EI-Female scores for each of the three hearing impaired groups undergoing V2T, including adult hearing aid users (HA-T2), adult cochlear implant recipients (CIA-T2), and pediatric cochlear implant recipients (CIC-T2). '*' indicates the difference between the paired groups is significant at 0.05 level.

Results for the EI-Both test revealed a statistically significant training effect for both HA-T2 [t(6) = -3.18, p = 0.01] and CIA-T2 [t(7) = -2.43, p = 0.04] groups (see Figure 37).

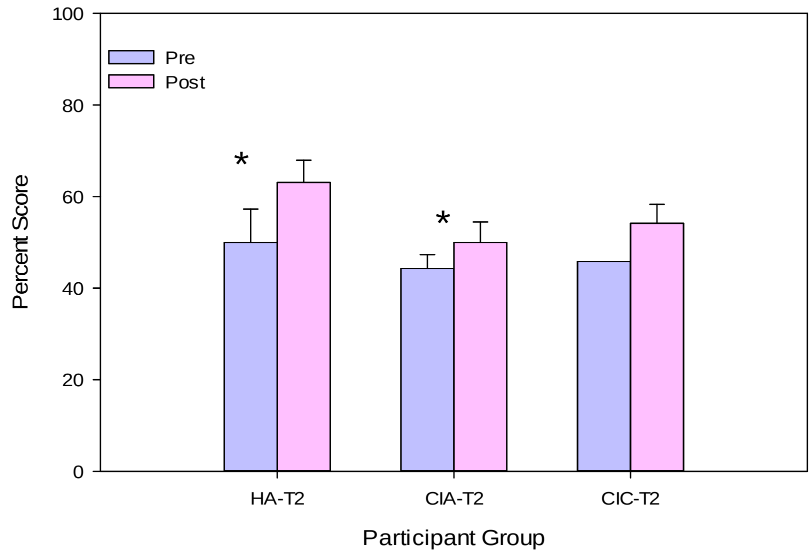

Figure 37. Means and standard errors (in error bars) for the pre- and post-training EI-Both test scores for the HA-T2, CIA-T2, and CIC-T2 groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

(3) Question/Statement Identification Tests (Q/S-Male, Q/S-Female, & Q/S-Both)

Results for the pre- and post-training tests for Q/S-Male showed a significant training effect only for the HA-T2 group [t(6) = -4.22, p = 0.006]. As shown in Figure 38, the HA-T2 group showed an improvement in the Q/S identification test score following the completion of V2T. For the Q/S-Female scores, all of the hearing impaired participants who underwent V2T showed an increase in mean score after training (HA-T2: 8.34%; CIA-T2: 13.54%; CIC-T2: 25.01%). However, results from a series of paired t-tests failed to reveal a statistically significant training effect. For the Q/S-Both test scores, all of the hearing impaired participants trained with V2T also showed an improvement after training (HA-T2:

13.1%; CIA-T2: 9.38%; CIC-T2: 12.5%). A significant training effect was found for both HA-T2 [t(6) = -4.09, p = 0.006] and CIA-T2 [t(7) = -2.39, p = 0.048] groups (see Figure 39).

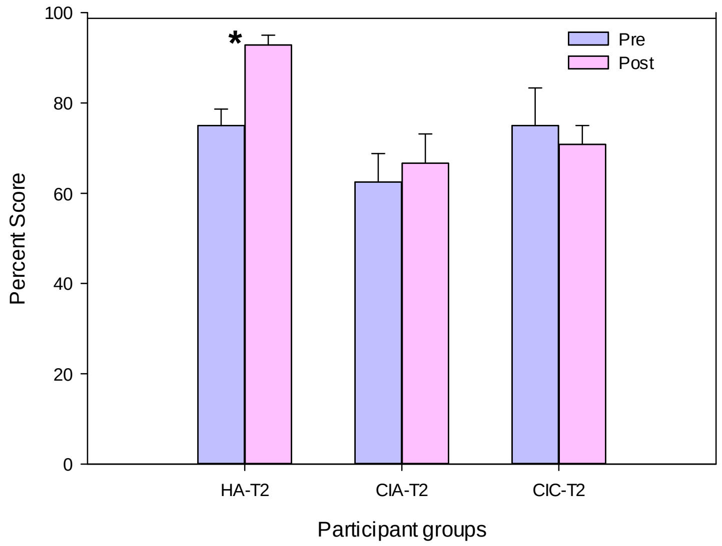

Figure 38. Means and standard errors for the pre- and post-training Q/S-Male test scores for the HA-T2, CIA-T2, and CIC-T2 groups. ‘*’ indicates the difference between the paired groups is significant at 0.05 level.

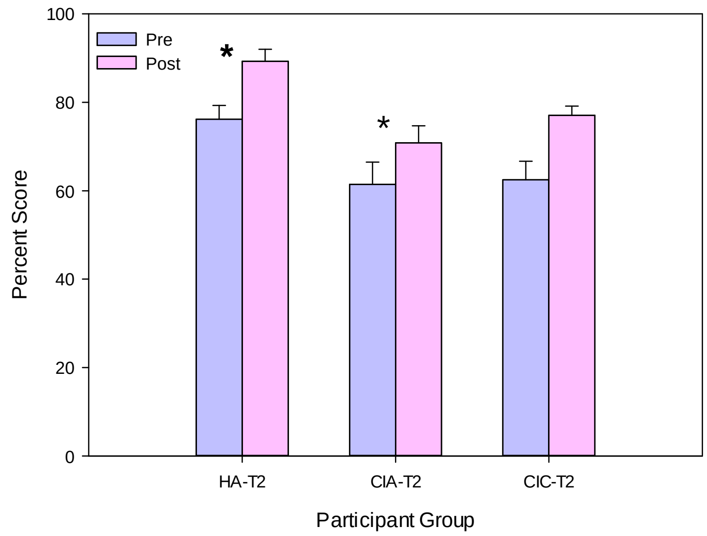

Figure 39. Means and standard errors (in error bars) for the pre- and post-training Q/S-Both test scores for the HA-T2, CIA-T2, and CIC-T2 groups. ‘*’ indicates the difference between the paired groups is significant at 0.05 level.

(4) Familiar Melody Identification Tests (FMI-Rh & FMI-NoRh)

The mean pre- and post-training FMI-Rh test scores for each of the three hearing impaired groups who underwent V2T are shown in Figure 40. The CIA-T2 group exhibited a significant training effect [$t(6) = -1.54$, $p = 0.01$], showing a mean increase of 5%. The HA-T2 participants scored 100% for their post-training test. No significant training effect was found for either HA-T2 or CIC-T2 groups.

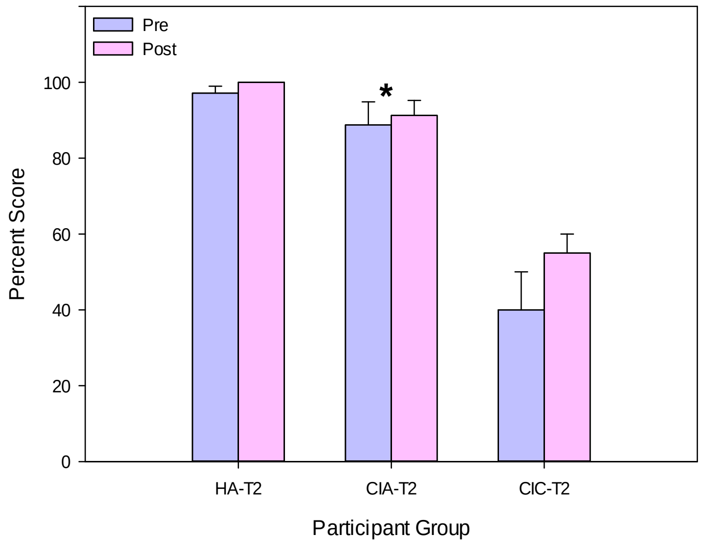

Figure 40. Means and standard errors (in error bars) for the pre- and post-training FMI-Rh test scores for the HA-T2, CIA-T2, and CIC-T2 groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

For the FMI-NoRh scores, all participants who underwent V2T showed an improvement after training (HA-T2: 14.3%; CIA-T2: 30%; CIC-T2: 20%). Results from a series of paired t-tests showed a significant training effect for the HA-T2 [$t(6) = -2.70$, $p = 0.03$] and CIA-T2 [$t(7) = -3.55$, $p < 0.01$] groups (see Figure 41).

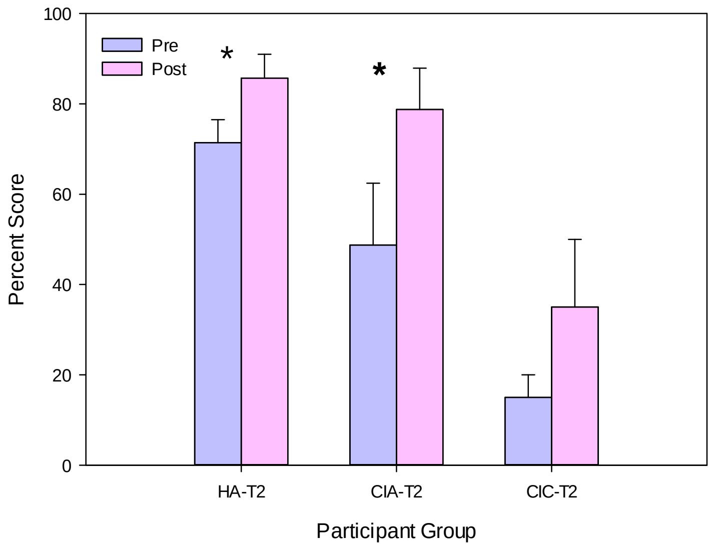

Figure 41. Means and standard errors (in error bars) for the pre- and post-training FMI-NoRh test scores for the HA-T2, CIA-T2, and CIC-T2 groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

For the InsI test scores, a significant training effect was found for both HA-T2 [t(6) = -5.72, p < 0.01] and CIA-T2 [t(7) = -3.53, p = 0.01] groups (see Figure 42).

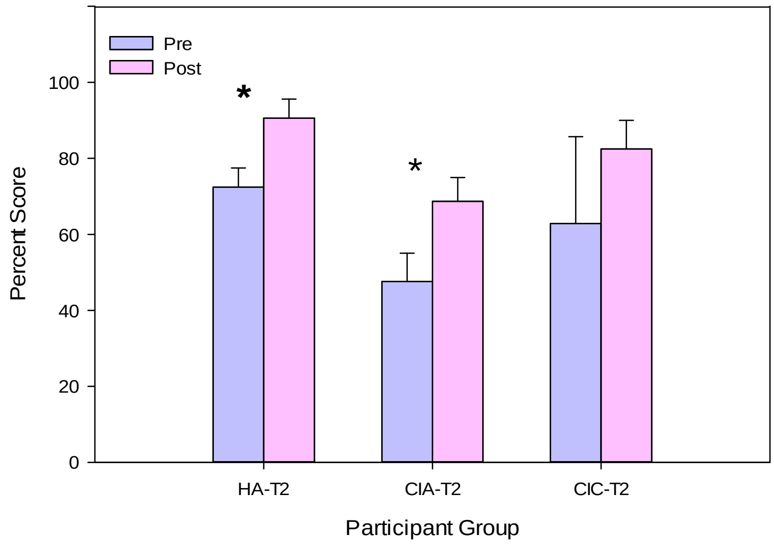

Figure 42. Means and standard errors (in error bars) for the pre- and post-training InsI test scores for the HA-T2, CIA-T2, and CIC-T2 groups. '*' indicates the difference between the paired groups is significant at 0.05 level.

(6) Pitch Ranking Test (PR)

No significant training effect was observed for any of the hearing impaired groups for the PR test scores. Both HA-T2 (11.31%) and CIA-T2 (7.79%) groups showed a non-significant slight improvement in their post-training scores while no change was found for the CIC-T2 group after V2T. Observations made in a follow-up investigation comparing the pre- and post-training PR test scores at individual semitone separation levels were shown in Appendix 14.

4.2.4 Correlation Analysis Results

Results from a series of correlation procedures conducted on a selection of attribute variables or test scores were reported for the CIA, HA, and CIC groups separately.

CIA Group

For the CIA group, correlation coefficients were obtained between pre-training test scores and five participant attribute variables, including (1) age, (2) sex, (3) time with CI, (4) duration of deafness pre CI, and (5) music score, which was calculated based on the experience and attendance in formal and informal music related tasks as mentioned in the musical background questionnaire (see Section 4.1). In addition, correlations between pre-training PR test scores and pre-training FMI-Rh, FMI-NoRh, EI-Male, EI-Female, EI-Both, Q/S-Male, Q/S-Female, Q/S-Both, and InsI test scores of CIA participants were also measured. Results revealed a significantly negative correlation ($r = -0.515$, $p = 0.004$) between age and the pre-training FMI-NoRh scores. A significantly positive correlation was observed between the pre-training PR test scores and the music scores ($r = 0.579$, $p = 0.018$) and between the pre-training PR test scores and the pre-training FMI-Rh test scores ($r = 0.512$, $p = 0.042$). No significant correlation was found between the other four attribute variables and the pre-training test scores for the CIA group as a whole.

The correlations between the five attribute variables and the post-training scores for both CIA-T1 and CIA-T2 groups were measured to evaluate the effect of these attributes on the training outcomes and the correlations between the post-training test scores were also investigated. A significantly positive correlation was found between the post-training PR scores and the post-training FMI-Rh ($r = 0.723$, $p = 0.042$), EI-Female ($r = 0.767$, $p = 0.002$), EI-Both ($r = 0.775$. $p = 0.002$), Q/S-Male ($r = 0.791$, $p = 0.019$), Q/S-Female ($r = 0.769$, $p = 0.027$), and Q/S-Both ($r = 0.082$, $p = 0.01$) test scores. No other significant correlation was found between the five attribute variables and the post-training scores for the

CIA-T1 group. Similarly, no significant correlation was found for the CIA-T2 group between any of the five attribute variables and the post-training test scores or between the post-training PR test scores and the post-training FMI-Rh, FMI-NoRh, EI-Male, EI-Female, EI-Both, Q/S-Male, Q/S-Female, Q/S-Both, and InsI test scores. No significant correlation was found between the music scores and any of the post-training test scores for either CIA-T1 or CIA-T2 group.

HA Group

For the HA group, correlation coefficients were obtained between the pre-training test scores and five participant attribute variables, including (1) age, (2) sex, (3) the average number of hours HA was worn per day, (4) the average number of years HA had been worn, (4) PTA scores, and (5) music score. In addition, correlations between pre-training PR test scores and pre-training FMI-Rh, FMI-NoRh, EI-Male, EI-Female, EI-Both, Q/S-Male, Q/S-Female, Q/S-Both and InsI test scores were also measured. No significant correlation was found between any of the five attribute variables and any of the pre-training test scores for the HA group as a whole.

For the HA-T1 group, age had a significantly positive correlation with both post-training Q/S-Female ($r = 0.686$, $p = 0.0280$) and PR ($r = 0.717$, $p = 0.019$) test scores. Post-training PR test scores showed a significantly positive correlation, in the HA-T1 group, with post-training Q/S-Female ($r = 0.069$, $p = 0.001$) and Q/S-Both ($r = 0.68$, $p = 0.029$) test scores.

For the HA-T2 group, the average number of hours the HA was worn per day positively correlated with the post-training EI-male ($r = 0.86$, $p = 0.01$) test scores.

CIC Group

For the CIC group, correlation coefficients were obtained between the pre-training test scores and six participant attribute variables, including (1) age, (2) sex, (3) the age at which the hearing loss was diagnosed, (4) the age the at which the HAs were fitted, (5) the age at which the CI surgery was done, and (6) music score. Additionally, the correlations between pre-training pitch ranking test scores and pre-training FMI-Rh, FMI-NoRh, EI-Male, EI-Female, EI-Both, Q/S-Male, Q/S-Female, Q/S-Both, and InsI test scores were also measured. Results revealed a significant positive correlation between age and pre-training EI-Both test scores ($r = 0.875$, $p = 0.023$). No significant correlation was observed between the other attribute variables and pre-training test scores.

With V1T, the post-training PR test scores showed a significant positive correlation with age ($r = 1.00$, $p < 0.001$), indicating that older CIC-T1 participants performed better than younger CIC-T1 participants in the PR task. The age at which the HAs were fitted showed a significant negative correlation with the CNC-word post-training test scores, indicating that the younger the age at which the CIC-T1 participants were fitted with HAs, the better the pitch perception training could help improve their performance in the CNC-Word identification task. No other significant correlation was found between the other attribute variables and post-training test scores for the CIC-T1 group. Correlation analyses could not be carried out for the CIC-T2 group due to a small sample size.

4.2.5 Summary of Objective Test Results

A general summary of the findings obtained from the pre-training versus post-training test performance is provided in Table 9. As shown in Table 9, there was a general tendency for participants trained with V2T to show a statistically significant improvement in more tests than those trained with V1T. Among all three hearing impaired groups, the HA participants showed the most improvement after training with either V1T or V2T. The CIC group was the least responsive to the training effect.

Table 9. Summary of the training outcomes for the HA, CIA, and CIC groups undergoing V1T and V2T in the selected tests of speech and music perception. The test showing a significant training effect is marked with an asterisk (*).

	HA		CIA		CIC	
Test	V1T	V2T	V1T	V2T	V1T	V2T
CUNY						
CNC-W						
CNC-Ph	*				*	
FMI-Rh				*		
FMI-NoRh		*		*		
InsI		*	*	*		
PR						
EI-Male	*					
EI-Female	*	*		*		
EI-Both	*	*	*	*		
Q/S-Male		*				
Q/S-Female	*					
Q/S-Both		*		*		

4.3 Data Logging Information

This section summarizes the information obtained from the data logger in the pitch perception training program used for tracking details about the training process of the HA (n = 17), CIA (n = 16), and CIC participants (n = 5). Both versions of the training program contained a data logging feature that recorded details about each trainee's use of the program and progression throughout the training. These results are described in three main sections: (1) task training details, which included the time spent on each of the three training modules, namely, pitch ranking, odd-one-out, and pitch contour, (2) instrument training details, which included the time spent on each of the selected musical instruments and male and female sung vowels /a, e, i, o, u/, and (3) difficulty level training details, which included the percent-correct score obtained by participant groups for each sung vowel/instrument across twelve difficulty levels.

4.3.1 Task Training Details

This section provides a summary of the total number of hours spent on training and the average score (i.e. percentage of correct answers) for the computerized pitch ranking tests achieved by the CIA, HA and CIC participant groups undergoing V1T and V2T, respectively. It is important to reiterate that the all the training participants were requested to complete a total of 20 hours of training. As shown in Table 10, participant groups who underwent V1T trained for more hours, on average, compared to those who trained with V2T. It can be observed from Table 11 that, for both V1T and V2T, the HA group obtained the highest score and the CIC group the lowest.

Table 10. Means and standard deviations of the total number of hours spent by each of the three hearing impaired groups (CIA, HA, & CIC) which underwent V1T and V2T, respectively.

	V1T		V2T	
	Mean	SD	Mean	SD
CIA	18.67	5.29	15.03	9.33
HA	16.47	5.45	15.63	6.27
CIC	19.31	1.17	2.38	0.06

Table 11. Means and standard deviations of the total score (i.e., percentage of correct answers) achieved by each of the three hearing impaired groups (CIA, HA, & CIC) which underwent V1T and V2T, respectively.

	V1T		V2T	
	Mean	SD	Mean	SD
CIA	92.15	7.39	86.24	13.77
HA	98.95	0.34	96.10	2.48
CIC	80.48	8.58	81.96	11.04

The time spent and the score for each of the three main modules (i.e., pitch ranking, odd-one-out, and pitch contour) for each of the three participant groups (CIA, HA, and CIC) are illustrated in Figure 43 for both versions of the training program. As shown in Figure 43a, the CIA participants who underwent V1T spent the longest time on the PR module, while the HA and CIC participants who underwent V1T spent the longest time on both PR and PC modules (see Figure 43a). With V2T, the CIA participants spent the longest time on the PC module, while the HA and CIC participants who underwent V2T spent the longest time on the PR module (see Figure 43b). The HA participants were found to show the highest percentage of correct score and the CIC participants the lowest score in all of three modules either with V1T (see Figure 43c) or V2T (see Figure 43d).

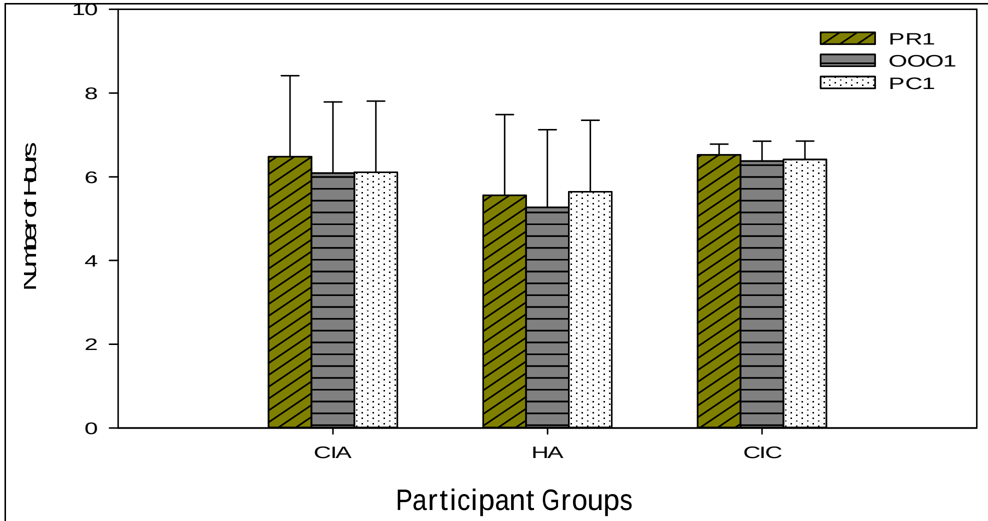

Figure 43a. Total number of hours spent - V1T.

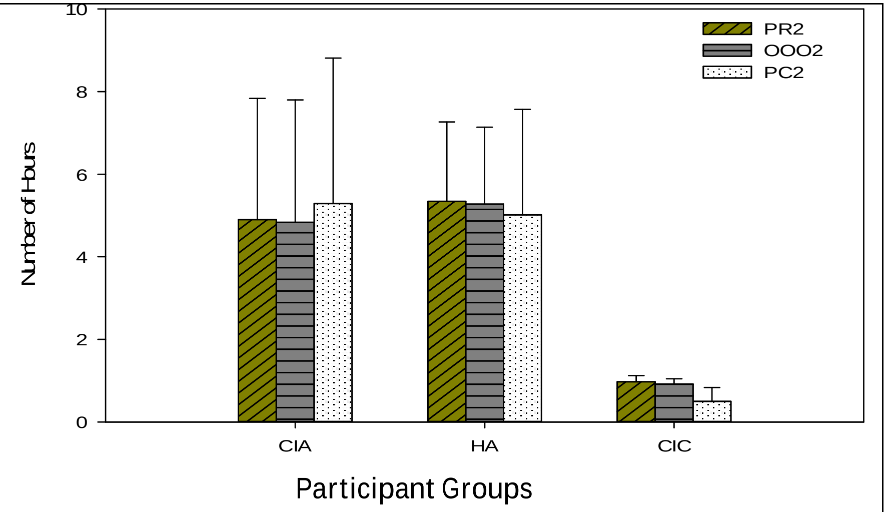

Figure 43b. Total number of hours spent - V2T.

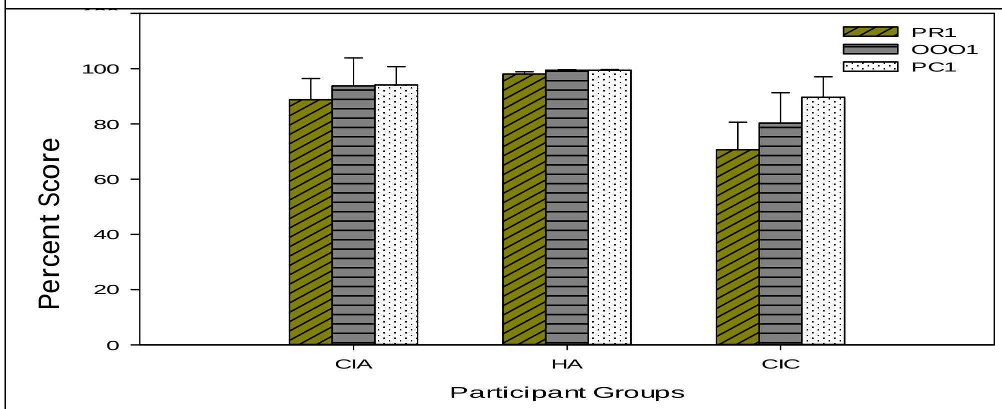

Figure 41c. Percentage score - V1T.

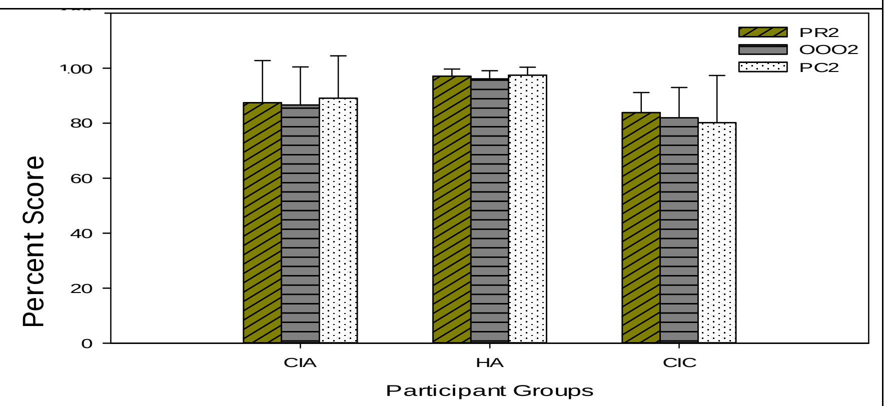

Figure 43d. Percentage score - V2T.

Figure 43. Means and standard deviations (in error bars) of the total number of hours spent in the training and percent-correct scores for CIA, HA, and CIC participant groups with V1T or V2T on the pitch ranking (PR), odd-one-out (OOO), and pitch contour (PC) modules.

4.3.2 Instrument Training Details

This section summarizes the total number of hours spent on training by the CIA, HA and CIC groups who underwent trainings with V1T and 2 programs respectively. With V1T, all of the participant groups trained on all of the instruments and sung vowels. With V1T, the CIA participants generally spent the longest time (hours) on Piano (M = 2.14) and Trumpet (M = 2.07), the HA participants on Trumpet (M = 1.66) and Piano (M = 1.36), and the CIC participants on Violin (M = 1.51) and Cello (M = 1.42). With V1T, the CIA participants spent the lowest amount of time on the male /u/ sound (M = 0.55), the HA participants on the male /o/ sound (M = 0.29), and the CIC participants on Clarinet-Bass (M = 0.47).

With V2T, the CIA participants spent the longest time (hours) on Male /a/ (M = 1.88), Piano (M = 1.44), and Flute (M = 1.28) and the HA participants on Piano (M = 1.82) and Clarinet-Soprano (M = 1.65). None of the CIC participants trained on Clarinet-Soprano or any of the sung vowels except for the male /u/ sound. Similar to the CIC participants who underwent V1T, the CIC participants who underwent V2T also spent the longest time (hours) on Cello (M = 1).

4.3.3 Difficulty Level Training Details

This section summarizes the score (i.e., percentage of correct answers) achieved for each instrument/sung vowel across difficulty levels (1-12 semitones) by the CIA, HA and CIC participant groups trained with V1T and 2 programs respectively. With V1T, the HA group obtained the highest average score (M = 97.59%, and CIC group the lowest average score (M = 73.17% for all the instruments and sung vowels. The CIA group obtained higher scores for Saxophone-Baritone (M = 96.67%), Male /i/ (Mean = 94.84%), and Saxophone-Soprano (M = 94.38%) among all of the stimulus types. The HA group achieved higher scores for Saxophone-Tenor (M = 99.52%), Female /i/ (M = 99.49%), and Saxophone-

Soprano (M = 99.46%). The CIC group received higher scores for Male /a/ (M = 85.64%), Male /u/ (M = 84.84%), and Saxophone-Soprano (M = 83.47%).

Similar observations were made for V2T. The HA participants who underwent V2T obtained the highest average score for most of the instruments except for Male /u/, Cello, and Saxophone- Soprano, where the CIC participants scored higher than the HA participants. The CIA participants who underwent V2T were best at recognizing Guitar (M = 93.16%), Male /o/ (M = 92.42%) and Male /u/ (M = 89.72%) among all the stimulus types. The HA participants who underwent V2T were best at recognizing Saxophone-Baritone (M = 98.1%), Male /i/ (M = 97.12%) and Female /a/ (M = 97.1%). The CIC participants who underwent V2T scored 100% for Saxophone-Soprano and Male /u/ sounds and 97.84% for Cello.

Among all the stimulus types, for V1T, the CIA participants who underwent V1T obtained the lowest scores on Clarinet-Bass (M= 81.16%), the HA participants on Flute (M = 86.61%), and the CIC participants on Clarinet-Bass (74.53%). With V2T, the CIA participants showed the lowest score on Female /e/ (M = 66.04%), the HA participants on Cello (M = 88.42%), and the CIC participants on Trumpet (64.7%).

In V1T, all three participant groups completed training across all difficulty levels. In V2T, both HA and CIA participant groups completed training across all difficulty levels while none of the CIC participants completed training at below six semitone levels.

All three participant groups who underwent V1T were found to complete training across 12 semitone levels only for Clarinet-Bass and for four male sung vowels. For V2T, both CIA and HA participants were found to complete training for all instruments across all difficulty levels except for Clarinet-Bass. It is noteworthy that four CIA recipients who were using bimodal stimulation and one CI-only participant completed training at all twelve difficulty levels. The remaining CI-only participants could not complete training beyond three semitone levels for the majority of the high-pitched instruments and female sung vowels. None of the CIC participants completed training for any of the instruments/sung vowels at all 12 difficulty levels.

4.3.4 Summary of Data Logging Results

The main findings of the computer data logging information are:

1. All of the participant groups undergoing V1T spent more time training than those who underwent V2T.
2. The HA participants received the highest percentage score and the CIC participants the lowest across all three training modules (pitch ranking, odd-one-out, and pitch contour) for both V1T and V2T.
3. All of the participant groups spent the longest time on the pitch ranking module for both V1T and V2T except that the CIA participants who underwent V2T spent the longest time on the pitch contour module.
4. All three participant groups undergoing V1T completed training in all the instruments/sung vowels available in the program.
5. Only the HA and CIA participant groups completed training across all instruments/sung vowels in V2T.
6. All participants who underwent V1T completed training across all difficulty levels.
7. Only the HA and CIA participant groups completed V2T across all difficulty levels.

4.4 Post-Training Program Evaluation Questionnaires

This section details the results obtained from the post-training evaluation questionnaires filled out by the HA, CIA and CIC groups who completed either version of the pitch perception training program. In addition, the CIC-parent group also completed the questionnaire to supplement the information provided by the CIC participants.

4.4.1 Itemized Questionnaire Results

The questionnaires were designed to obtain the respondents' views about (1) the benefits of the training program, (2) various aspects of the training program, (3) total amount of time the trainee spent on the training, and (5) duration and frequency of the training. A brief summary of the results for each of these areas is provided below.

Benefits of the Training Program

For V1T, all of the CIA, CIC, and CIC-parent groups and 80% of the HA group reported that the training was beneficial. For V2T, all of the CIA and HA participants, and one CIC (out of 2) and one CIC-parent (out of 2) also reported that the training was beneficial. When asked to rank the three modules of the V1T program in the order of perceived benefits, the 'pitch ranking' module was considered the most beneficial by the majority of all participant groups (HA: 80%; CIA: 62%; CIC-parent: 66%). The majority of the CIC group (66%) considered the 'odd-one-out' module and one CIC participant considered the 'pitch contour' module to be the most beneficial. For V2T, the majority of the CIC (100%), CIC-parent (100%), and CIA (75%) participants also reported that the 'pitch ranking' module was the most beneficial. However, for V2T, 57% of the HA group considered the 'pitch contour' module to be the most beneficial.

Various Aspects of the Training Program

Results regarding the participants' views about the training program were organized into nine categories, including (1) usefulness, (2) variety of the tasks used in the program, (3) ease of understanding instructions given in the training program, (4) ease of following instructions given in the training program, (5) ease of understanding instructions given in the training manual, (6) pictures used in the training program, (7) instruments used in the training program, (8) support provided during training, and (9) overall opinion of the training program. Participants rated these aspects on a five point scale (1 = very poor, 2 = poor, 3 = neutral, 4 = good, and 5 = very good). The distribution of the ratings is illustrated in Figure 44 for V1T and in Figure 45 for V2T for each of the participant groups. Observations regarding the ratings on each of the nine categories of the training program were detailed as follows.

Usefulness. For V1T, the majority of the CIA and CIC-parent group rated the 'usefulness' of the training program as 'good' while the majority of the HA group reported 'neutral'. For V2T, the majority of the CIA and HA groups rated the 'usefulness' of the training program as 'very good' and 100% of the CIC-parent group rated it as 'good'. Unlike their parents, the CIC participants tended to give a lower rating to 'usefulness' with either V1T or V2T.

Variety. For V1T, the majority of the HA participants rated the variety of the program as 'neutral' and the majority of the CIA participants rated it as either 'good' or 'very good' . For V2T, the majority of the HA and CIA participants rated 'variety' as 'very good'. Both CIC and CIC-parent groups gave a lower rating to 'variety' as compared to the other participant groups. Overall, V2T received a higher rating in 'variety' than V1T.

Ease of Understanding Instructions. For both V1T and V2T, the majority of the CIA, HA, CIC, and CIC-parent participants rated the ease of understanding instructions given in the training program as ‘good’ or ‘very good’.

Ease of Following Instructions. For both versions, the majority of HA, CIA, CIC, and CIC-parent groups considered the ease of following instructions in the training program to be ‘very good’.

Ease of Understanding Training Manual. For both versions, HA, CIA, CIC, and CIC-parent groups rated the ease of understanding the training manual as ‘very good’.

Pictures Used in the Training Program. The majority of the CIA, HA, and CIC-parent groups reported that the pictures used in either V1T or V2T were ‘good’ or ‘very good’. The two CIC participants undergoing V2T expressed different views from their parents about the pictures, with one indicating ‘neutral’ and the other rating it as ‘poor’.

Instruments Used in the Training Program. The musical instruments used in both versions of the training program were generally considered either ‘very good’ or ‘good’ by the HA and CIC-parent groups. In contrast, the CIC participants trained with either V1T or V2T remained ‘neutral’ in rating the instruments used in the program.

Support Provided during Training. For V1T, the majority of the CIA and CIC-parent participants rated the support provided during the training as either ‘very good’ or ‘good’ while the majority of the HA and CIC participants remained ‘neutral’. For V2T, the majority of the CIA, HA, and CIC-parents (one out of two) participants rated the support provided during training as ‘very good’ while both of the CIC participants remained ‘neutral’.

Overall Opinion. The overall opinion about the training program differed between participant groups. For V1T, the majority of the CIA participants rated the training as ‘very good’ and the majority of the CIC participants and all of their parents rated it as ‘good’ while the majority of the HA participants remained ‘neutral’. For V2T, the majority of the HA participants and one CIC-parent participant rated the training as ‘very good’, one CIC participant and one CIC-parent participant rated it as ‘good’ while the majority of the CIA participants reported ‘neutral’ and one CIC participant rated it as ‘very poor’.

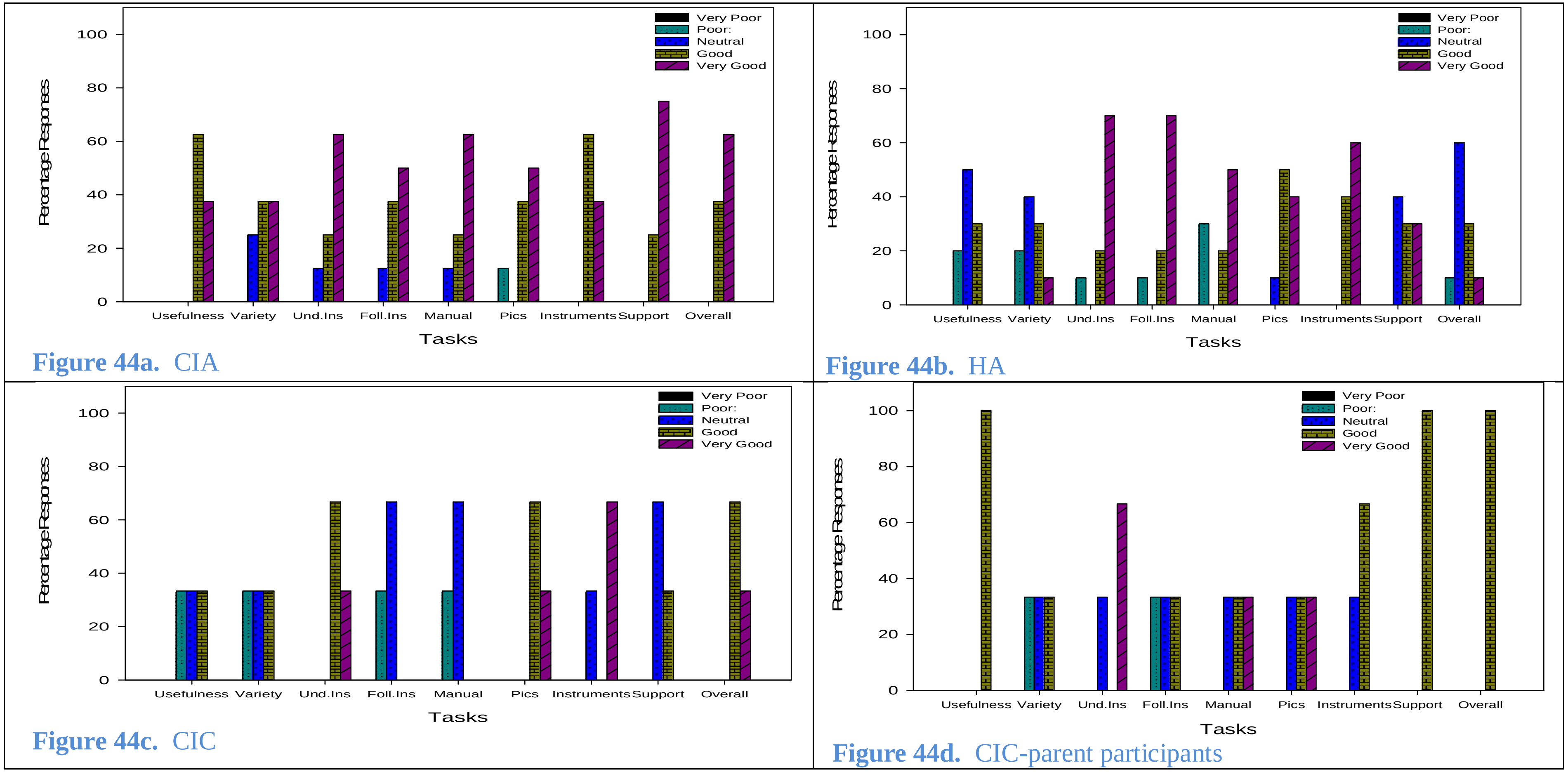

Figure 44a. CIA

Figure 44b. HA

Figure 44c. CIC

Figure 44d. CIC-parent participants

Figure 44. The percentage of participants found in each of the five rating categories (‘very poor’, ‘poor’, ‘neutral’, ‘good’, and ‘very good’) for the CIA, HA, CIC, and CIC-parent groups separately in assessing the V1T program. The participants were asked to evaluate (1) usefulness, (2) variety of the tasks, (3) ease of understanding instructions (Und.Ins), (4) ease of following instructions (Foll.Ins), (5) ease of understanding instructions given in the training manual (Manual), (6) pictures used in the training program (Pics), (7) instruments used in the training program (Instrument), (8) support provided during training (Support), and (9) overall opinion of the training program (Overall).

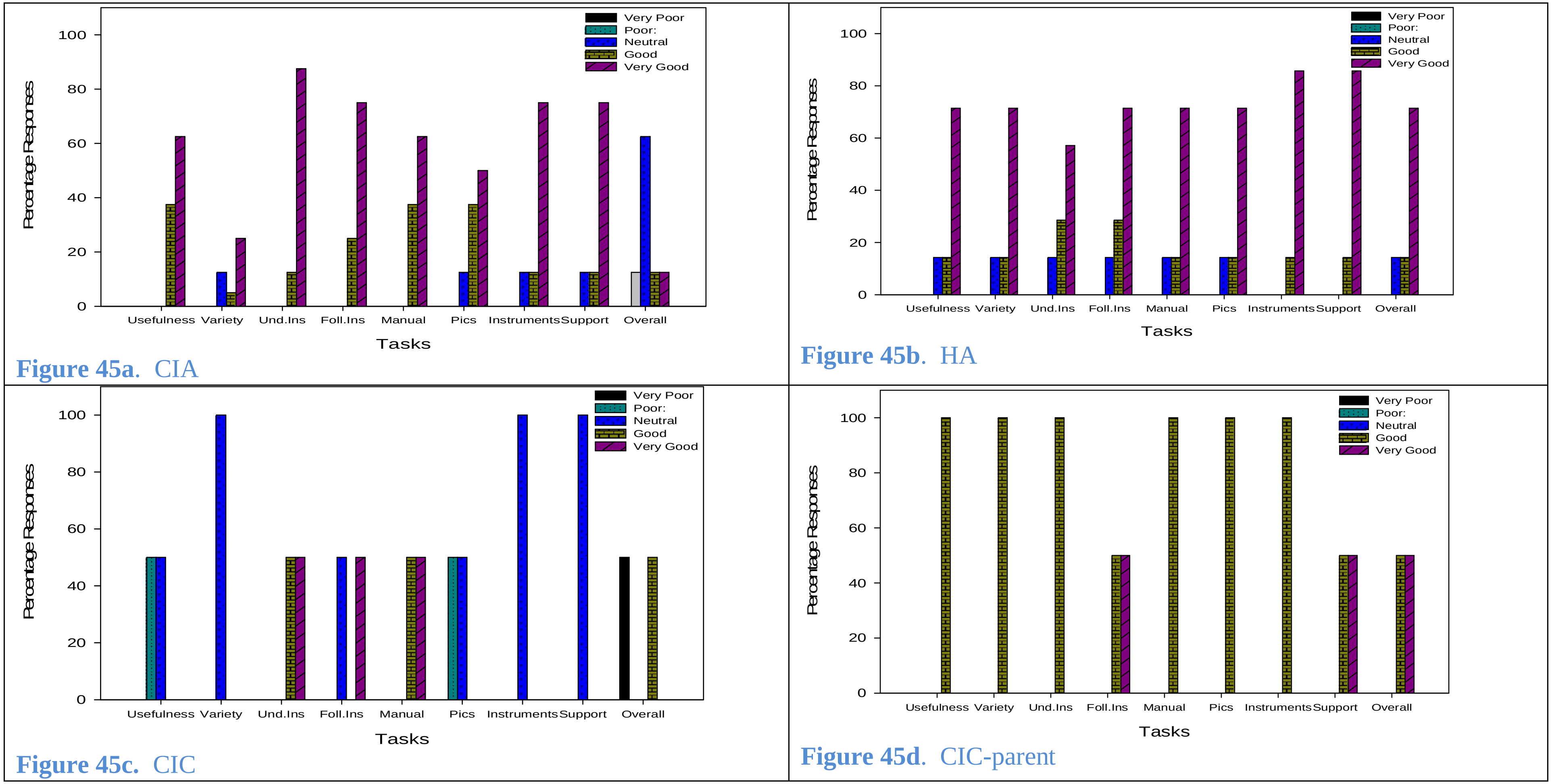

Figure 45. The percentage of participants found in each of the five rating categories (‘very poor’, ‘poor’, ‘neutral’, ‘good’, and ‘very good’) for the CIA, HA, CIC, and CIC-parent groups separately in assessing the V2T program.

Total Amount of Time Spent on the Training Program

The average amount of time spent on the training per session as reported by the CIA, HA, CIC, and CIC-parent participants is summarized in Table 12. On average, the group that spent the longest time per session was the HA group when trained with V1T and the CIA group when trained with V2T. The CIC group was the group which spent the least amount of time per session with either V1T or V2T.

Table 12. Means and standard deviations of the time (in minutes) spent in training per session as reported by all four groups (CIA, HA, CIC, and CIC-parent) for V1T and V2T respectively.

	V1T		V2T	
	Mean	SD	Mean	SD
CIA	28.13	7.53	36.25	22.00
HA	30.45	1.50	31.67	4.08
CIC	26.67	5.77	27.50	10.60
CIC-parent	30.00	0.00	17.50	17.67

Duration and Frequency of the Training

The CIA, HA, CIC, and CIC-parent participants were asked to indicate, on a five-point scale, whether they considered 'ten weeks of training', 'thirty minutes per training session', or 'four sessions per week' to be 'long', 'too long', 'neutral', 'short', or 'too short'. Specific observations are listed as follows.

Ten Weeks of Training. For V1T, between 30-66% of the participants in various groups reported that 'ten weeks of training' was 'long'. For V2T, at least half of the participants in each group reported that 'ten weeks of training' was either 'long' or 'neutral'. None of the participants using either version reported that the 10 weeks of training was short.

Thirty Minutes per Training Session. The majority of all the participant groups using either V1T or V2T of the training program reported that a '30-minute training session' was either 'long' or 'neutral'. None of the participants rated the sessions as 'short' in duration.

Four Sessions per Week. The majority of participants in each group reported to be 'neutral' regarding using the program 'four sessions per week'. None of the participants rated the sessions as 'short'.

4.4.2 Improvement in Pitch-Related Identifications after Training

To assess the effect of training on the ease of performing pitch-related identifications, participants were asked, after the training, to rate on a 5-point scale ('strongly disagree', 'disagree', 'neither agree nor disagree', 'agree', and 'strongly agree') in response to the question as to whether they perceived improvement in performing various pitch-related identification tasks. The 11 pitch-related identification tasks, which were the same as the ones the participants were asked to rate before training, included the MSp, MSin, FSp, FSin, Sp-N, Sin-M, In-Sp, In-Sin, Q/S, FM, and EI tasks. Results for the subjective evaluation of the training effect on these pitch-related perception tasks were reported for the three hearing impaired groups separately as follows.

HA Participants. The majority of the HA participants who underwent V1T did not find any improvement or decline in performance in all of the listed tasks. In contrast, the majority of the HA participants who underwent V2T responded 'agree' to the question in all of the listed tasks except for the 'Sp-N' task, where the majority reported 'neither'.

CIA Participants. For both V1T and V2T CIA trainees, the majority of the participants reported 'neither agree nor disagree' in the 'Sp-N', 'Sin-M', 'In-Sp', and 'In-Sin' identification tasks. Overall, regardless of the version of the program used, more participants reported that they 'agree' perceiving an improvement in pitch-related music and speech perception tasks following training.

CIC and CIC-Parent Participants. Overall, the majority of the CIC and CIC-parent participants reported that they did not find any improvement in performance of any of the pitch-related tasks following training with V1T or V2T.

4.4.3 Summary of Post-Training Questionnaire Results

The major findings of this questionnaire were as follows:

1. The majority of the participants in each group (CIA, HA, CIC, and CIC-parent) found both versions of the training program beneficial and the ‘pitch ranking’ module the most beneficial task.
2. The majority of the participants in each group rated many aspects (7/8) of the two versions of the program as ‘very good’.
3. The majority of all participant groups undergoing V1T reported that they trained ‘four times a week’ while the majority undergoing V2T reported that they trained ‘more than four times a week’.
4. Ten weeks of training was generally considered ‘long’ by the majority of all participant groups trained with either V1T or V2T. However, the majority of all trainees remained ‘neutral’ about ‘30 minutes per training session and four training sessions per week’.
5. A self-perceived improvement in performing various pitch-related identification tasks was generally indicated by the majority of the three hearing impaired training groups and the CIC-parent participants. Positive responses were most evident in the HA group, followed by the CIA group and the two CIC groups (CIC and CIC-parent).

CHAPTER 5: DISCUSSION

The purpose of this study was to develop an effective computerized pitch-perception training program to improve the pitch-related speech and music perception skills of hearing impaired children and adults. The program was pilot tested on postlingually deafened adult CI recipients, postlingually hearing impaired hearing aid users, and prelingually deafened pediatric CI recipients. This chapter discusses the results obtained from all three hearing impaired groups (CIC, CIA, and HA) and the two NH groups (NHA and NHC) in relation to the five main hypotheses.

5.1 Hypotheses One and Two

Hypothesis 1: *The NHA group will perform better than the HA and CIA groups and the NHC group will perform significantly better than the CIC group in the baseline pre-training test measures of speech and music perception.*

Hypothesis 2: *The HA group will perform better than the CIA group in the baseline pre-training test measures.*

Results obtained from the pre-training test measures partially support these two hypotheses. Discussions specific to each of the tests pertaining to these hypotheses are provided below.

Speech-in-Noise Tests (CUNY, CNC-W, and CNC-Ph)

As the first hypothesis predicted, the NHA participants performed better than the CIA, and HA groups and the NHC participants performed significantly better than the NHC group on all of the Speech-in-Noise tests. To identify speech in background noise, a listener needs to differentiate between speech and noise and attend only to the speech signal (Tyler et al., 2010). Speech perception in noise requires encoding of the fine spectral characteristics of speech. For speech perception in noise, the spectral resolution needs to be even finer than what is required to understand speech in quieter listening situations (Fu et al., 1998a). However, sensorineural hearing loss alters the way signals are processed by the peripheral hearing mechanism resulting in changes at the cortical level (Moore & Amitay, 2007). These alterations include: increase in hearing thresholds, broadening of cochlear filters, and re-organization of the neuronal connections of the cortical and sub-cortical areas (Tremblay, 2007). Listeners with cochlear hearing loss are unable to take advantage of the temporal and spectral "dips" of background noise in recognizing speech-in-noise conditions (Moore, 2007). While a normally functioning cochlea has auditory filters covering the entire range of speech frequencies, the broadening of auditory filters due to cochlear hearing loss leads to poor frequency resolution (Glasberg & Moore, 1986; Moore, 2007). Moore (1996) reported that broadening of the bandwidth of the auditory filter to twice that in normal hearing resulted in an increase of hearing thresholds of more than 40 dBHL. In addition, compared to unilateral adult (6/16 participants used bimodal stimulation) and pediatric CI recipients, NH individuals have the advantage of binaural hearing in perceiving speech in noisy backgrounds (Dillon, 2001). These factors could have contributed to the poor performance observed in all three hearing impaired groups compared to both groups of NH participants

An alternative explanation of the poor performance observed in the three hearing impaired groups for the Speech-in-Noise tests is to consider the technical limitations of the auditory prostheses, including CI and HA. Cochlear implants were initially designed to assist the hearing impaired in speech perception by capturing or enhancing the spectral characteristics of speech (Gfeller at al., 2000a). However, current speech processing devices use few channels to deliver the frequency information across the entire spectral range to the cochlea. The limited number of electrodes and spectral channels used by current speech processing strategies results in loss of spectral and temporal fine structure characteristics of the speech signal (Fu & Nogaki, 2005c; Fu et al., 1998b). Both postlingually deafened adult (Fetterman & Domico, 2002) and prelingually deafened pediatric CI recipients (Dawson et al., 1992; Dowell, Blamey & Clark, 1995) are known to demonstrate excellent open-set speech discrimination in quiet. However, speech perception in noise remains a challenge for both adult (Fetterman & Domico, 2002; Galvin et al., 2007; Gfeller et al., 1998b; Gfeller et al., 2007; M.L. Grasmeder & M.E. Lutman, 2006; Kong et al., 2004a; Sucher & McDermott, 2007; Turner, Gantz, Vidal, Behrens, & Henry, 2004a) and pediatric CI recipients (Psarros et al., 2002;Wawroski, 2008). The CI recipients require at least 4 to 6 spectral channels for recognizing speech in quiet listening conditions and even larger number of spectral channels for speech recognition in noise conditions (Friesen et al., 2001; Fu et al., 1998b). Furthermore, poor spectral and frequency resolution, strong channel interaction (Turner et al., 2004), and mismatched representation of the frequency of the CI's filter and the corresponding characteristic frequency in the cochlea may reduce an implant recipient's ability to recognize speech in noisy backgrounds (Friesen et al., 2001; Turner et al., 2004).

In addition to the technical limitation of the CI systems, listener attributes may also impact on speech perception in noise. Pediatric CI recipients are either born with, or have acquired, a severe-to-profound sensorineural hearing loss. They grow up listening to sounds through their CIs. However, current speech processing strategies do not provide an accurate or "full" representation of the complex acoustic signal (McDermott, 2004; Zeng, 2002). The diminished input provided by the CI device may compromise the development of the auditory system in pediatric CI recipients. In addition, pediatric CI recipients have been found to perform poorer than NH children in short-term memory tasks (Pisoni & Cleary, 2004). Both of these factors could also have contributed to the significantly poorer scores observed for the CIC participants compared to the NHC participants in the present study.

Having difficulty perceiving speech-in-noise is a common problem faced by many hearing aid users (Chung, 2004a; Kochkin, 2002; Nordrum et al., 2006). Killion (1997) reported that the amount of signal-to-noise enhancement required by a hearing impaired individual depends on the degree of the hearing loss. Individuals with mild-to-moderate hearing loss require an enhancement of 4 to 6 dB in signal-to-noise ratio and those with a severe-to-profound hearing loss require 8-12 dB improvement in signal-to-noise ratio compared to normal hearing listeners (Killion, 1997). Many HA manufacturers currently use directional microphones and/or digital-noise-reduction algorithms to improve speech perception in noise in hearing aid users (Chung, 2004; Nordrum et al., 2006). These strategies are designed to improve the signal-to-noise ratio for the audio input to improve speech perception in noise in hearing aid users. The digital-noise-reduction schemes have been reported to improve the "listening comfort"; however, there is no evidence showing that they help to significantly improve speech perception in noisy situations (Alcántara et al., 20003; Walden et al., 2000) The use of directional microphones can help improve the perception of speech-in-noise by increasing the signal-to-noise ratio for the audio input.

However, the amount of improvement depends on a number of factors, such as the amount of reverberation in the environment, number of noise sources, the distance between the noise source and the listener, and the number and placement of the directional microphones (Bentler et al., 2004; Novick et al, 2001; Wouters et al., 1999). Although these strategies may help perceive speech-in-noise, there is great variability in the strategies, algorithms, types, and microphone designs used in HAs among manufacturers. The present finding of a poorer average score for speech perception in noise in the HA group compared to the NHA group is attributable to the technical limitations of the HA devices in not effectively transmitting speech cues in the presence of background noise as well as the inadequacy of the impaired auditory system in effectively coding the speech cues as a consequence of the SNHL.

In regard to the second hypothesis, the HA participants performed significantly better than CIA participant group in all of the Speech-in-Noise tests. Three possible explanations are offered for this finding: (1) binaural advantage (2) representation of low frequency information, and (3) disadvantages of electric hearing in combination with the technical limitations of the CI. Firstly, bilateral hearing aid users have an advantage over unilateral CI recipients in perceiving speech-in-noise because bilateral hearing aid users are capable of taking advantage of binaural hearing, such as head shadow effect, binaural redundancy, binaural squelch effect, and spatial unmaking (Ching et al., 2001, 2006; Ching, 2005; Dillon, 2001; Mok et al., 2007) as well as better localization of sounds in the horizontal plane (Byrne & Noble, 1998).

Secondly, the temporal fine structure and F0 information help speech perception in the presence of fluctuating background noise. In the present study, it is likely that the hearing aid users were capable of taking advantage of low-frequency pitch cues, which can be used in segregating the F0 information of competing sounds (Kong et al., 2005). The HAs provide adequate low-frequency information regarding the F0, whereas CI-alone is not capable of providing adequate fine structure voice pitch information at low frequencies (Kong et al., 2005). Additionally, CI-alone provides neither masking release (i.e., the ability to perceive speech in the presence of fluctuating background noise as in the case of a competing speaker) (Oxenham, 2008; Stickney et al., 2004) nor adequate F0 information to separate speech from competing speaker noise (Stickney et al., 2004). It is noteworthy mentioning that among the 16 CIA recipients who participated in this study, six of them used bimodal stimulation in the present study. The binaural processing mechanisms mentioned before and the availability of the low-frequency pitch cues with the use of a HA in the CIA recipients using bimodal stimulation help improve their performance in speech-perception-in noise tasks (Ching et al., 2001, 2004b, 2005; Kong et al., 2004b). However, even with six CIA participants using bimodal stimulation, the overall pre-training results of the CIA participant group remained significantly poorer than the HA participant group, suggesting that the difficulties of CI recipients in perceiving speech-in-noise may not be fully compensated with bimodal stimulation and/or that inclusion of a greater number of CI recipients using bimodal stimulation is needed for further investigation.

Finally, it is possible that differences between electric and acoustic hearing also contribute to the poorer results observed in the CIA group compared to the HA group. The CI stimulates hearing electrically while the HA stimulates hearing acoustically. The technical limitations of the CI systems in transmitting complex acoustic signals could have collectively contributed to the significantly poorer results observed in the CIA group as compared to the NHA and HA groups.

Emotion Identification Tests (EI-Male, EI-Female & EI-Both)

For all three emotion identification tasks, the NHA group performed significantly better than both CIA and HA groups and the NHC group performed significantly better than the CIC group as predicted in the first hypothesis. This finding agrees with previous studies showing that the emotion identification abilities of adult hearing aid users are significantly poorer than those of NH adults (Most & Aviner, 2009; Pereira, 1996) and that adult and pediatric CI recipients perform significantly poorer than their NH counterparts (Luo et al., 2007; Most & Aviner, 2009; Peters, 2006; Schorr, 2004). The ability to perceive emotions is vital for effective communication and social interactions and one's ability to perceive vocal expression plays an important role in interpreting emotions expressed in speech (Banse & Scherer, 1996; Most & Aviner, 2009). Listeners can identify emotions based on auditory as well as non-verbal visual cues (Banse & Scherer, 1996). Results from a follow-up acoustic analysis of the testing items used in this study agree with past research that changes in F0, duration, and amplitude provide substantial cues for differentiating between happy, sad, angry, and neutral emotions (Banse& Scherer, 1996). The details of the analysis fall outside the scope of this thesis. In general, 'happy' was associated with a higher F0, increased F0 range, increased F1 (i.e., the first formant frequency, which corresponds to vowel openness/height), increased jitter (i.e., cycle-to-cycle pitch variation in vocal fold vibration) and shimmer (cycle-to-cycle amplitude variation), and decreased voice projection power. 'Sad' was associated with increased loudness, decreased voice projection power, and increased F0 range, whereas 'angry' was associated with a higher mean F0 and decreased jitter and shimmer values. Changes in F0, F0 range, and F1 are salient cues for emotion identification (Luo et al., 2007). The CI recipients perceive duration cues fairly well through their speech processors. However, they may have limited access to other acoustic parameters of the speech signal due to the poor spectrotemporal resolution of the CI (Luo et al., 2007). Consequently, CI recipients may rely primarily on intensity cues to differentiate between emotions (House, 1994; Luo et al., 2007; Pereira, 2000a). The poor performance of CI recipients in differentiating between emotions could again be attributed to the inability of the implant to accurately present low frequency F0 information (Most & Aviner, 2009). The majority of HA participants in the present study had hearing losses ranging from mild to moderately-severe. Moore (1996) reported that SNHL above 40 dBHL could result in broadening of auditory filters. This could affect the cochlea's function in resolving the lower harmonics of complex sounds for extracting the F0 information. Therefore, difficulties experienced by the present groups of hearing impaired participants in perceiving pitch and the complexity of the task requiring a listener to pay attention to subtle acoustic parameters could have affected the performance of these participants.

Results of the present study can also be explained in the context of developmental maturation. The ability to perceive and interpret emotions develops when an infant is exposed to spoken utterances (Walker-Andrews & Lennon, 1991). Infants can correctly discriminate between positive and negative vocal expressions by the age of five months (Walker-Andrews & Lennon, 1991). Infants learn to identify emotions by watching facial expressions while paying attention to matching auditory inputs (Walker-Andrews & Lennon, 1991). During the first year of life, infants learn to interpret different emotions

(Schorr, 2004). The interaction between the parent/caregiver and child in a social environment plays a major role in emotional development of children (Schorr, 2004). During the second and third years of life, children take an active role in situations that facilitate emotional development (Dunn & Munn, 1987). As children grow older, they learn to carry out a conversation regarding their feeling states and understand other's emotions (Dunn et al., 1991). As prelingually deafened children are either born with a congenital hearing loss or acquire hearing loss at a very young age, they may not have similar opportunities as NH children to verbally interact with their parents/caregivers or peers. Dyck et al. (2004) reported a significant delay in acquiring the emotional recognition skills by the hearing-impaired compared to age-matched NH children and adolescents. Boyd et al. (2000) reported that pediatric CI recipients display less social interaction compared to their NH peers. In addition to the technical limitations of the CI device, these delays in the development of emotion recognition skills could also have contributed to the significantly poorer test scores obtained by the present group of CIC participants compared to NHC participants.

The second hypothesis was rejected for the EI task, with no significant differences in scores found between HA and CIA participants for all three emotion identification tasks. The results of the current study are in agreement with the previous findings that no comparable difference was observed for the emotion identification task between young CI recipients and hearing aid users (Most & Aviner, 2009) and postlingually hearing impaired adult CI recipients and hearing aid users (Pereira, 2000a). Limited access to pitch and spectral cues through a CI could have contributed to the poor scores obtained by both adult and pediatric CI recipients in the emotion identification tests (Luo et al., 2007). Most and

Aviner (2009) reported that the acoustic information that conveys the emotional state of the utterances can be found in the low frequency region, where hearing aid users have their residual hearing. Looi et al. (2008c) found that CIA recipients perform significantly better ($p = 0.035$) in pitch ranking of male sung vowels than in pitch ranking of female sung vowels. It has also been shown that low frequency temporal pitch cues could be obtained from the amplitude modulation in the frequency region below 300 Hz (McKay et al., 1994, 1995). Since the mean F0 of each of the voice stimuli used in the EI tests in this study ranged between 90 and 320 Hz, it is posited that the CIA recipients might not have much difficulties in performing the EI task if it mainly required identifying pitch cues in the low-frequency region. Hence, it is not surprising that CIA recipients performed comparably to hearing aid users in EI task. However, it appears that the complexity of the other acoustic parameters involved in the differentiation of emotions still poses some challenges to both CI recipients and hearing users.

Question/Statement Identification Tests (Q/S-Male, Q/S-Female, & Q/S-Both)

As the first hypothesis predicted, the NHA group performed significantly better than the CIA group and the NHC participants also scored significantly better than the CIC group in all three Q/S identification tests. However, no significant difference was observed between the NHA and HA groups for the scores in any of the three Q/S tests. These findings agree with the previous observation in intonation identification tasks that NH adults perform better than adult CI recipients (Meister et al., 2009) and NHC perform better than CIC (Peng et al., 200). A follow-up acoustic analysis of the test sentences used in the present study indicated that the acoustic features of the female voice were more prominent than the male voice. For example, when the F0 range of the pitch contour of an utterance was compared between questions and statements within each of the speakers used in this study to produce the stimuli for the Q/S identification tests, no significant difference was found for the two male speakers. However, a significant difference in the mean F0 range was found for both female speakers [Speaker one: $t(3, 4.52) = 32.64$, $p < 0.0001$; Speaker two: $t(3, 4.42) = 40.09$, $p < 0.001$]. This could explain the better, but not significant, scores achieved by all of the participant groups for female voice than for male voice in Q/S identification. Variations in intonation are mainly related to changes in F0, glottal source amplitude, and speech spectrum (Pickett et al., 1999). Accurate perception of the speaking pitch primarily involves the extracting of F0 information from the complex acoustic signal. For a listener to extract this information, one of two different mechanisms can be used: (1) resolving the individual frequency components present in the signal and (2) extracting the temporal pitch information from the signal (McDermott, 2004; Looi, 2008b). Both of these mechanisms are affected when the acoustic signal is processed through speech processors in CIs (Looi, 2008b). The significantly poorer results obtained by the CI groups compared to the NH peer groups could be due to the inability of the CI recipients to extract F0 information to differentiate between questions and statements.

As the second hypothesis predicted, the HA group performed significantly better than the CIA group in the Q/S tests. Speech intonation can be perceived through changes in the F0 and the time-energy envelope of the speech signal (Most & Paleed, 2007; Richardson et al., 1998). Based on a finding showing that young hearing aid users performed better than young CI recipients in question identification, it has been suggested that hearing aid users can detect changes in F0 and in time-energy envelope (Most & Paleed, 2007). The present finding of a better performance by the HA group in differentiating between questions and statements compared the CIA group confirms the notion that the F0 information, as well as the time-energy envelope information, is accessible to the hearing aid users (Kong et al., 2005). These findings suggest that hearing aid users have better access to the low frequency information needed for differentiating between questions and statements compared to CI recipients.

Familiar Melody Identification Test-with and without Rhythm (FMI-Rh & FMI-NoRh)

As the first hypothesis predicted, the NHA group performed significantly better than the CIA group and the NHC group performed significantly better than the CIC group in the FMI-Rh and FMI-NoRh tests. However, no significant difference in scores was observed between the HA and NHA groups for these tests. Currently there are no studies that have directly compared adult hearing aid users with NH listeners on their melody identification abilities. However, although Looi et al. (2008c) did not directly compare hearing aid users with NH listeners, the FMI tests used in the Looi et al.'s study (2008c) was validated with NH adults, with the choice of familiar melodies used in the tests based on the responses obtained from NH adults. Therefore, it could be assumed that the average score for the FMI tests would be close to 100% for NH adults (Looi et al., 2008c). In Looi et al. (2008c) study, HA participants scored 91% correct on the FMI-Rh test. Hence, the present finding of a non-significant difference between the HA and NA groups in the FMI tests can be considered to be in agreement with the findings of Looi et al (2008c). It is likely that a combination of factors such as the advantages of binaural hearing (Dillon, 2004) and pitch cues provided by low frequency residual hearing (Dorman et al., 2008;

Sucher & McDermott, 2009) contributed to the similar performance between HA and NH groups.

The present finding of a generally poorer performance of the CI groups compared to the NH peer groups agrees with existing studies employing the familiar melody identification task with intact rhythm cues for both adults (Gfeller et al., 2002a; Kong et al., 2004a) and children (Vongpaisal et al., 2006, 2009). A NH listener can use relative interval size, overall pitch contour, and rhythmic duration cues to identify melodies (Dowling & Bartlett, 1981). Pijl (1997) reported that the speech processing strategies utilized in the CI devices did not provide precise pitch information that can be used to collectively or sequentially to determine the interval size of melodic pitch. Pitch interval information gets lost as the acoustic signal is processed through speech processors in CI recipients (Pijl, 1997). Many implant recipients do not have a precise or similar frequency-to pitch relationship as in normal hearing listeners (Geller et al., 2000a). Hence, pitch contour information and the exact interval size may be degraded or may not be accurately presented to implant recipients, making familiar melody identification a difficult task for the CI recipients (Gfeller, 1998c).

Across all participant groups, it was found that performance in the FMI-Rh test was better than in the FMI-NoRh test. In particular, both CIA and CIC groups performed better in the FMI-Rh test than in the FMI-NoRh test. The HA group performed significantly higher than the CIA group only in the FMI-NoRh test but not in the FMI-Rh test. These results confirm the previous finding that adult CI recipients perform slightly better in familiar melody identification tests when rhythm cues are intact than when rhythm cues are removed (Gfeller et al., 2002a; Kong, Stickney, & Zeng, 2005).

Mitani et al. (2007), Nakata et al. (2005), and Vongpaisal et al. (2009 and 2006) reported that even though rhythm cues facilitate melody recognition, those cues are insufficient to help pediatric CI recipients to achieve the same scores as their NH peers in familiar melody identification task. This may explain why the CIC group performed significantly lower than the NHC group in both FMI-Rh and FMI-NoRh tests. Past listening experience plays an important role in identifying familiar melodies in cochlear implantees (Gfeller et al., 2003). The pediatric CI recipients have very limited or no memory of listening to familiar melodies through acoustic hearing and grow up listening to familiar melodies through their CI. Hence, pediatric CI recipients may not have the same internal representation of sounds as that established through acoustic hearing (Looi, 2008b). All of the NHC participants in this study had more than 5 years of training in formal music training, attended music classes at school, and were also engaging in musical activities such as choir, band, or orchestra. However, only one CIC participant attended music classes at school, three (out of 6) took part in informal music related tasks, and four took part in formal music activities. When the amount of participation in music-related tasks was compared between the CIC and NHC groups, the NHC group was found to have more experience in engagement in music-related tasks than the CIC group. The significantly poorer scores exhibited by the CIC group compared to the NHC group in the FMI-Rh and FMI-NoRh tests could be due to not only the technical limitation of the CI but also the lack of experience in music listening.

The non-significant difference between the CIA and HA groups for the FMI-Rh test can be explained in terms of the following factors. Firstly, existing research reports that both adult CI recipients and hearing aid users perform comparably in rhythm identification tasks (Looi et al., 2008c). In addition, it was found that adult CI recipients performed comparably to adult NH listeners in rhythm perception tasks (Gfeller et al., 2000b; Gfeller & Lansing, 1992, 1991; Gfeller et al., 1997). It is posited that adult hearing aid users could also perform comparably to adult NH listeners. Secondly, existing research suggests that the use of a HA in the contra-lateral ear, in addition to a CI, can enhance the abilities of CI recipients in performing tasks of pitch perception and familiar melody recognition (Dorman et al., 2008; Gfeller et al., 2008; Kong et al., 2004b, 2005). The benefits the HA can provide have been discussed previously. In this study, a total of six CIA participants were receiving bi-modal stimulation and one CIA participant was also receiving electro-acoustic stimulation. This could have helped improve the overall performance score of the CIA recipients in FMI-Rh task. These factors could have contributed to the comparable the FMI-Rh scores between the CIA and HA participants in this study. When rhythm cues were removed from the stimuli, the performance of the CIA participants was found to significantly deteriorate, which supports the above statement on the importance of rhythm cues for implant recipients. It is also posited that when pitch cues are degraded, CIA recipients rely on the rhythm cues for familiar melody identification. These results confirm the previous finding that CI recipients rely on rhythm cues for familiar melody identification (Fujita & Ito., 1999; Gfeller et al., 2005; Gfeller et al., 2002a).

Familiar Musical Instrument Identification Test (InsI)

As the first hypothesis predicted, NHA participants scored significantly better than the CIA participants, however, no significant differences were observed between NHA participants and the HA participants. A significant difference was observed between the NHC and the CIC participants. Therefore, Hypothesis One is partially supported. An instrument recognition task was used to measure timbre perception. Timbre is the characteristic that allows a listener to differentiate between notes having the same pitch, loudness and duration played by different musical instruments (Grasmeder & Lutman, 2006). Hence, factors that are required for the accurate pitch perception might have affected the timbre perception of the CI participants. In addition, factors such as the spread of current around the electrodes and the reduction in the number of surviving spiral ganglion neurons may lead to perceptual smearing of the input acoustic signal (McDermott, 2004). Both the inability of the speech processing strategies to apply fine spectral analysis of the input acoustic signal and the perceptual smearing could affect the timbre perception in CI recipients (McDermott, 2004). In agreement with past research (Gfeller et al., 2002a; Grasmeder & Lutman., 2006; McDermott & Looi, 2004), results from this study showed that CIA participants performed less accurately on instrument identification tasks than their NH peers. However, past research suggests that, even with the limitation of the current CI devices, timbre perception can be improved with training (Gfeller et al., 2002b). From the responses shown in the musical background questionnaires, it was noted that four out of the six CIC participants were involved in formal music training with their CI. In contrast, only one of the CIA participants had musical training after receiving their CI. In addition, CIC participants were more actively engaged in music related activities such as singing, playing an instrument, and/or listening to recorded music than CIA participants. This could explain the slightly better scores obtained by CIC participants than CIA participants. It is important to reiterate that the observed superior performance on the InsI task by the NHC participants could have resulted from them having had formal music training for more than 5 years and having been engaged in playing musical instruments. Due to the technical limitations of the CI, however, along with less experience in taking part in music-related tasks compared to the NHC listeners, the CIC participants were not able to match the performance of NHC participants who had experience in formal music training.

The second hypothesis is accepted as the HA participants performed significantly better on the InsI test compared to the CIA participants. As for the comparison between the CIA and HA groups, findings from the present study did not agree with the results reported the Looi et al.'s (2008c) study, who found no significant difference between adult HA and CI users. The conflicting findings are likely due to differences in the subject characteristics of the HA participants used in the two studies. The HA participants in the Looi et al.'s (2008c) study had bilateral moderately severe-to-profound SNHL, whereas the majority of the HA participants in the current study had hearing loss ranging from mild to moderately-severe SNHL. In addition, some of participants in the Looi et al.'s (2008c) study used unilateral HAs while all of the HA participants of the present study were bilateral hearing aid users. Better hearing abilities combined with advantages of binaural hearing (Dillon, 2001) could have resulted in the better InsI test scores obtained by the HA group in the present study.

Pitch Ranking Test

No significant difference in scores was observed between the NHA and HA groups. However, the CI groups recorded significantly poorer scores compared to their NH peers. Pitch ranking refers to the ability to judge, after listening to a pair of tones presented in sequence, which one is higher/lower than the other (McDermott, 2004). The poorer performance of the CI groups was expected because pitch information is not effectively transmitted through a CI (Gfeller et al., 2000a). A CI device produces a weak representation of voice F0 (Cullington & Zeng, 2008). Existing literature suggests that cochlear hearing loss (PTA $\geq$ 40 dBHL) results in auditory filters twice as large as that of NH (Moore, 1996). This results in reduced ability to resolve lower order harmonics of a complex signal affecting pitch perception (Arehart, 1994; Bernstein & Oxenham, 2006). Results obtained from this study confirm past reports that CI recipients perform significantly poorer in pitch ranking tasks than their NH peers (Gfeller et al., 2002a; Gfeller et al., 1997; Looi & Radford, 2011; Sucher & McDermott, 2007).

No significant difference was found between HA and CIA groups for the pre-training PR test, hence the second hypothesis is rejected. Results obtained in the current study for the PR test scores with all semitone separation levels averaged together do not agree with those of Looi et al. (2008c), who found that adult hearing aid users performed significantly better than adult CI recipients in ranking the pitch of sung vowels at 12, 6, and 3 semitones apart. Looi and Radford (2011) also reported that young hearing aid users performed better than young CI recipients in pitch ranking tests at the 12 and 6 semitone levels. In the present study, the HA group did show a higher average PR test score than the CI groups but the difference was not statistically significant. The pitch ranking task of the current study contained sung vowels ranging from 1 to 12 semitone separation levels and results were averaged across all 12 semitone separation levels. Thus, it is difficult to compare the average PR scores obtained in the present study with other studies in regards to specific semitone separation levels. Results from a follow-up analysis of the PR test scores at individual semitone separation levels did show some significant differences between the HA and both CI groups on the baseline measures, with the HA group performing significantly better than both CI groups at some semitone separation levels, especially if the scores were adjusted to correct the 'guessing' effect (see Appendix 14). It was also found that the HA participants performed comparably to NHA across all 12 semitone levels and the scores were significant ($p < 0.005$) above 50% chance level of performance. These results agree with the Looi et al (2008c) results that HA participants performed significantly better than above chance levels at 12, 6, 3 semitone levels. When the same analysis was carried out on the CIA participants, it was revealed that they performed more poorly than the HA participants across all 12 semitone levels, however, they performed significantly better ($p < 0.05$) than the chance level between 12-6 semitone levels and also at the three semitone level. Looi et al. (2008c) found the CIA participants' scores to be significantly above chance levels at the 12 and 6 semitone levels but not at the three semitone level. There are some methodological differences, especially in the stimuli used, between the Looi et al (2008c) study and the present study. The female sung vowel /a/ was used in the current study and both female and male sung vowels /a/ and /i/ were used in Looi et al (2008c) study. Furthermore, only two presentations were used at each semitone level in this study. The small sample size may render the scores susceptible to the 'guessing' effect. These differences could have resulted in the better performance observed in the CIA recipients at the three semitone level if the scores were not adjusted to remove the ‘guessing’ effect.

5.2 Hypotheses Three and Four

Hypothesis 3: *The post-training test scores obtained by the V1T groups will be significantly higher than their pre-training test scores and the post-training scores of their control groups.*

Hypothesis 4*:* *The post-training test scores obtained by the V2T groups will be significantly higher than their pre-training test scores.*

Results obtained from pre- and post-training test measures partially support hypotheses 3 and 4. A specific discussion related to each of these hypotheses is provided below.

Speech-in-Noise Tests (CUNY, CNC-W & CNC-Ph)

Both hypotheses 3 and 4 were rejected as there was no significant improvement observed for Speech-in-Noise tests for any of the training groups using either the V1T or V2T of the pitch perception training program. One of the reasons for the lack of any training benefit observed in the all three hearing impaired training groups from their post-training scores may be due to the fact that pitch training provided by this training program would not have been sufficient to overcome the limitations of the device. Another reason could be that the musical pitch training may not generalize to the speech perception in noise. Identifying consonants in sentences and words could be difficult for hearing impaired listeners due to perceptual deficits (Revoile et al., 1991). There is some evidence that “top-down” sentence recognition training in noise can improve hearing aid users’ sentence recognition in noise (Kricos, Holmes and Doyle, 1992). Top-down training refers to the breaking down of a system into its compositional sub-systems using prior knowledge of the properties and dependencies of the objects in it. And the bottom-up approach combines the fine information together to form a grander system (Davis, 2007). It is assumed that tasks used in both V1T and V2T of the pitch perception training program incorporated both top-down and bottom-up approaches. For example, in pitch discrimination and odd-one-out tasks, participants had to focus on the differences in the acoustic parameters to differently identify the stimuli. However, in the pitch-contour task, they had to focus on the overall pitch contour to differently identify the correct response. Even though both versions of the pitch perception training program used both top-down and bottom up approaches, neither V1T nor V2T in this study focused specifically on training speech perception in noise. In general, it would seem that more specific training involving phoneme, word, and sentence training in noise may be required to bring out a significant improvement in word and sentence identification in noise for hearing aid users as well as CI recipients. The lack of improvement noted across the training groups was not unexpected.

Emotion Identification Test (EI-Male, EI-Female & EI-Both)

Results obtained from participant groups trained with V1T provided partial support for Hypothesis Three. Participants of the HA training group scored significantly better post-training than pre-training and significantly better than the control group for all three emotion identification tasks. Participants in the CIA training group showed a significant improvement in post-training scores of the EI-Both test. However, they did not score significantly better than the control group participants for any of the EI tests. The CIC group trained with V1T failed to show any significant improvement in post-training scores for any of the tests and also failed to show any significant training effect over the control group.

Results obtained from participants trained with V2T for the emotion identification tests partially support Hypothesis Four. The HA and CIA trained with V2T showed significant improvement in EI-Female and EI-Both tasks. The CIC group trained with V2T failed to show any significant improvement for any of the tests.

Both prosody and melody perception rely on accurate perception of the F0, duration and amplitude information (Schon et al., 2004). Extensive musical pitch perception training has been known to facilitate pitch perception in spoken language (Besson et al., 2007). Past literature suggests that similar neural systems are involved in pitch processing of both music and speech (Schon et al., 2004, 2010). In the present study, it is proposed that pitch perception training could have helped the HA group to improve their skills in perceiving the F0 changes associated with the differentiation between emotions.

It was interesting to observe during emotion identification testing that CIA and CIC participants appeared to rely on the content information of the test sentences to guess the underlying emotion. For example, they repeated the test utterances and seemed to ponder over them many times trying to guess what sort of an emotional situation would use such content words. These observations are consistent with the suggestion that CI participants have difficulty perceiving pitch and spectral cues resulting in lower accuracy in identifying emotions. Current speech processing strategies effectively transmit the spectral envelope of input acoustic signals but not the fine structure pitch information required for accurate pitch perception (McDermott, 2004). Tremblay et al. (1998) reported that training effects would be first seen in underlying neural mechanisms rather than the behavioural results. Neural activities that took place during training might not be integrated and re-organized enough to be observed during behavioral testing (Tremblay et al., 1998). Furthermore, it was observed during testing that none of the CIC participants in this study appeared to understand that emotions could be detected through auditory cues alone. They might tend to rely on non-verbal facial expressions, gestures, and content information to identify the underlying emotions of a speaker. One's ability to successfully recognize the emotion carried in speech may be related to emotional intelligence rather than musical training (Trimmer & Cuddy, 2008). It is most likely that better outcomes from training could be achieved if the CIC participants trained with either V1T or V2T had a better understanding about identifying emotions through hearing alone. It is speculated that the CIA participants might have a better understanding of identifying emotions through auditory cues alone compared to the CIC group and thus they were able to gain greater benefits through auditory training than the CIC training group. This was evident in the significant post-training improvement observed for the CIA group trained with V1T on the EI-Both test and the CIA group trained with V2T on the EI-Female and EI-Both tests. The improvement observed for the CIA group trained with V2T could be due to the differences between V1T and V2T in that the former employed a fixed-level training approach while the latter employed an adaptive method. This difference will be further discussed in the discussion regarding Hypothesis Five (Section 5.3).

Fu and Galvin (2007a) highlighted the importance of completing an adequate number of training sessions over a period of time. Although the training groups of both

V1T and V2T were requested to complete 20 hours of training, the data logging information showed that none of the CIC participants trained with V2T completed training with all of the instruments and sung vowels. The CIC group trained with V1T completed an average of 19.31 hours of training while the CIC group trained with V2T completed o an average of only 2.38 hours of training. As the CIC group trained with V1T did not show any significant improvement in the post-training test scores for any of the EI tasks, it is posited that they did not benefit from the fixed-level pitch perception training even though they completed an adequate number of training hours. However, other extraneous factors and the technical limitations of the CI device as mentioned before could have also contributed to the observed lack of improvement in the CIC group trained with V1T. It remains unclear as to whether the CIC group trained with V2T, which employed an adaptive training protocol, would have obtained the full benefits of the training program as they did not complete the required number of training hours. The poor performance of the CIC group trained with V2T in the post-training emotion identification tests could also be reflective of a lack of sufficient training.

Question/Statement Identification Test (Q/S-Male, Q/S-Female, Q/S-Both)

Slow F0 changes in a sentence contribute to speech prosody and provide information to differentiate a question from a statement (Meyer et al., 2002). Results obtained for all three V1T groups failed to support the prediction of Hypothesis Three that V1T would help improve the participants' abilities to differentiate questions from statements. None of the V1T groups showed significant post-training improvement for any of the Q/S tests. Examination of the pre-training baseline results revealed a ceiling effect for the HA training group. Even though improved post-training scores were observed for the HA training group in all three Q/S tasks, it was hard to determine the extent of the pitch-perception training benefit given this pre-training ceiling effect. As for the two CI groups, it appears that the pitch-perception training provided through V1T was not sufficient to overcome the technical limitation of the current speech processing strategies.

The results obtained for the CIC participants do not agree with the past findings of Klieve and Jeanes (2001). These researchers evaluated the effect of prosodic training on six 7-12 year-old CIC participants. Subjects attended 40-minute training sessions twice a week for 10 successive weeks. This program focused on training participants to help improve their skills in detecting the prosodic cues in a linguistic context. Results revealed a significant post-training improvement in prosodic perception, including both emotion identification and Q/S identification. Training provided in the current study differs from Klieve and Jeans (2001) because it provided only pitch-perception training, not specific training pertaining to prosody perception in a linguistic context. Interestingly, it was also observed that none of the CIC participants in the current study had the prior knowledge that the questions and statements can be differentiated based on auditory cues. They reportedly relied on linguistic information and other non-verbal cues to differentiate a question from a statement. Therefore, it is possible that prosodic perception requires linguistic-specific training. In the case of pediatric CI recipients, they may require specific training to help them understand the concept of differentiating between questions and statement based on auditory cues alone. Since the pitch-perceptual training program used in the present study is not delivered in a speech context, learning through the present training program may not be easily generalized to the speech text.

Results obtained from all three participant groups who underwent V2T for the Q/S tests provide partial support for Hypothesis Four. The HA participants revealed a significant improvement for both Q/S-Male and Q/S-Both tests. The CIA participants revealed a significant improvement for the Q/S-Female and Q/S-Both tests. No significant improvement was observed for the CIC group trained with V2T. Although the CIC participants trained with V2T did not show an improvement in the post-training Q/S identification test score, it is quite likely that their poor performance was due to the reduced amount of training undertaken and the lack of concept of differentiating questions from statements based on auditory cues alone.

In general, the V2T program showed a positive training effect for the HA and CIA participants. From the data logging information, it was found that the V2T participants completed training across all 12-semitone levels, whereas the V1T participants completed the training across all 12-semitone levels for male sung vowels and clarinet-bass instrument only. It is possible that the better improvement observed in the V2T group could be related to the completion of training across all 12 semitone levels in a gradual manner across a large frequency range. The improvement in the ability to utilize the voice pitch cues was evident in both CIA and HA groups trained with V2T. The majority of the hearing aid users had mild hearing loss in the low frequency region. Some only had minimal hearing loss in the low frequency region. Hence, it is not surprising that they benefitted from pitch perception training more in the low-frequency region as evidenced by the significant improvement observed in their post-training Q/S-Male test scores. Fu et al (2005b) reported that CIA participants have difficulty in detecting subtle F0 changes due to the limited spectral resolution provided by the CI speech processors. In the current study, as there was not much difference between the mean F0 values of the questions and statements for male voice, it is assumed that pitch perception training was not sufficient to facilitate improvement in the Q/S-Male test scores due to the limited spectral resolution provided by the speech processing strategies in effectively transmitting pitch cues required to identify subtle voice pitch changes. Different to the results observed for the Q/S-Male test stimuli, there was a significant difference on the mean F0 range of the pitch contour between the question and statement stimuli used in the Q/S-Female tests. Hence, it is possible that despite the technical limitations of CIs, the pitch perception training can help improve the ability to detect a large change of F0 as evidenced by the significant post-training improvement in the Q/S-Female test scores found in the CIA group. Another possibility is that the CIA participants had poorer scores for the Q/S-female voice than the Q/S-Male voice to begin with and thus the post-training improvement was more evident in the Q/S-Female test. Additionally, the variability among the Q/S-Male voice test scores was higher than the Q/S-Female voice test scores. This could have also contributed to the non-significant finding of the training effect in the Q/S-Male test.

Familiar Melody Identification Test (FMI-Rh & FMI-NoRh)

None of the training groups involved in V1T showed a significant improvement in the post-training scores for the FMI-Rh or FMI-NoRh test. Hence, Hypothesis Three was rejected. Hypothesis Four was partially accepted. No significant improvement was found for the CIC participants trained with V2T. The HA-T2 participants showed a significant improvement for the FMI-NoRh test only. The CIA-T2 participants showed a significant training effect for both FMI-Rh and FMI-NoRh tests.

The reason for the lack of a noticeable improvement for the HA-T1 group in the post-training familiar melody identification test is not readily apparent. One reason could be that all of the HA-T1 participants showed a ceiling effect for the FMI-Rh test and eight (out of 10) HA-T1 participants also showed a ceiling effect for the FMI-NoRh test. Hence, it is no surprise that no further improvement was observed following training. Similar to the HA-T1 group, all of the HA-T2 participants also showed a ceiling effect for the pre-training FMI-Rh test scores. Hence, it is difficult to conclude whether V2T helped improve familiar melody identification in HA-T2 participants. On the contrary, there was a significant improvement observed for the HA-T2 group in the post-training familiar melody identification test scores when the rhythm cues were removed. In the absence of a ceiling effect for the HA-T2 group in the pre-training FMI-NoRh test scores, it is possible to conclude that V2T helped improve the familiar melody identification skills of hearing aid users.

It is also possible to speculate that pitch information provided through the CI is not sufficient, or that the rhythm information was too dominant (i.e., all that the CI participants were listening to). For the HA-T1 group, the fact they improved on the NoRh test but not the Rh test may be that when rhythm cues are present, they tend to dominate (i.e. participants focus on this), so the effect of training pitch is only apparent when the rhythm cues are left out.

Melody perception relies on the ability of listeners to accurately perceive interval size, pitch contour and the rhythmic duration cues (Dowling and Bartlett, 1981). When rhythm cues were removed, listeners have to rely on pitch contour and interval size cues to identify the melodies. Massaro et al. (1980) reported that pitch contour information is sufficient to identify familiar melodies even in the absence of tone height (tone's frequency) and chroma (position of a note within a musical scale). The current training program developed for this study provided training on pitch contour identification, pitch raking and pitch discrimination across different interval sizes. At present, there is no existing literature that has examined the effect of pitch training on the familiar melody identification abilities of hearing aid users. However, research suggests that in NH listeners music training facilitates pitch processing in music which can be corroborated by cortical changes seen in imaging studies (Besson et al., 2007; Schon et al., 2004). The improvement observed in melody recognition of HA-T2 group may be due to the improved ability to perceive melodic contour and/or the relative interval sizes.

Four (out of eight) CIA-T1 participants also showed a ceiling effect for the FMI-Rh test and two showed a floor-effect for the FMI-NoRh test. It is posited that for the FMI-Rh test, as more than 50% of the training participants scored above 90% in the pre-training test, even if the training had provided some improvement in the familiar melody identification test, it would not have been reflected in the post-training test scores. For the FMI-No Rh test, there was a large discrepancy between the results obtained from those two participants who showed the floor effect and the results obtained from the rest of the CIA-T1 group. Even though both of these participants showed a slight improvement in their post-training FMI-NoRh test scores, their scores could have affected the average post-training NoRh test scores leading to no significant improvement following training for the CIA-T1 group.

Findings from this study agree with those from the study of Galvin et al. (2007) who showed a significant improvement (20.8%) in familiar melody identification test devoid of rhythm cues for CIA participants. There are a number of reasons that could have contributed to the significant improvement observed in the CIA-T2 group. Fujita and Ito (1999) reported that previous musical training helps postlingually deafened adult CI participants to identify familiar melodies with and without vocal accompaniment. Gfeller et al. (2008) reported that musical training received during high school/adult years is associated with higher familiar melody identification scores. Results obtained from the Musical Background Questionnaire revealed that the majority of the HA-T2 participants had formal musical training and were also engaged in formal music related activities prior to receiving a CI compared to CIA-T1 group. This also could have contributed to the significant improvement observed in the CIA-T2 group. In addition, Gfeller et al. (2008) reported that wearing a HA in the contra-lateral ear assists with familiar melody identification tasks. Of the eight participants took part in the V2T, three CIA-T2 participants used bimodal stimulation and one participant used both hybrid EAS and bimodal stimulation. Collectively, these participants received a 10% improvement in FMI-Rh test scores and 25% in FMI-NoRh pre-to post-training test scores. There were only two CIA participants trained with V1T who had bimodal stimulation. Both of these participants showed a ceiling effect for the FMI-Rh test and collectively about 10% improvement was observed for the post-training FMI-NoRh test. This improvement would not have been sufficient to bring about a significant finding in the FMI-NoRh post-training test scores for the CIA group trained with V1T. These findings agree with Tremblay et al.'s (2007) findings. Tremblay et al. (1997) reported that training can generalize to listening situations beyond training sessions. Transfer of learning facilitates a listener to generalize the skill in detecting the changes in the acoustic signal of the training stimuli at the pre-attentive level to the perception of novel stimuli with similar acoustic parameters. All of these above mentioned factors could have contributed to improving the familiar melody identification with and without rhythm conditions in the CIA-T2 group.

In spite of the parental reports indicating that CIC participants enjoyed listening to music, none of the CIC training groups in this study showed a significant improvement following training. These results are in agreement with Nakata et al. (2005) and Vongpaisal et al. (2004b) studies. There are two possible reasons for the lack of improvement in the CIC participants in spite of the significant improvement found in the CIA participants. Firstly, the CIC participants may not have received ample training to express any benefit in identifying familiar melodies. An alternative reason is that similar to the CIA recipients, the CIC recipients may also not be able to perceive melodies as aesthetically ordered pitch patterns given the limited pitch cues that are available. Hence, they may be relying on lyrics to identify familiar melodies as evidenced by the better performance in identifying the commercial version of songs as opposed to the instrumental version and karaoke versions (Nakata et al., 2005). When the participants were asked, through the FMI questionnaires, whether they could identify a melody just by listening to it and whether they could sing it in their head, the CIA group scored significantly higher in the latter condition. Similar findings were obtained by Looi et al. (2003) for the FMI ability of adult CI recipients in Australian population. It is posited that even if the CIA group do not perceive familiar melodies precisely through their CI, the memory of the familiar melodies which they formed listening to melodies through their normal acoustic hearing mechanism prior to hearing loss could have helped them identify familiar melodies. For adult CI recipients, active auditory training may help minimize the spectral mismatch between the peripheral neural patterns and the central pitch templates acquired during normal hearing so that they can adapt to the acoustic signals perceived through their CI (Fu & Galvin, 2007a). This is evidenced by the significant improvement observed in the CIA-T2 group for both FMI tests. In contrast to the CIA group, the pediatric CI recipients form their memory of familiar melodies based on what they hear through their CI. As they cannot perceive the precise pitch information through their CIs, it is most likely that they may rely on lyrics and rhythm cues to identify melodies. Those cues were not available as the instrumental version of melodies were used in the FMI tests in the current study, hence, it is no surprise that the CIC recipients did not appear to gain any benefit from training in performing the FMI tasks.

Instrument Identification Test (InsI)

Both Hypotheses 3 and 4 are partially supported by the results obtained for the InsI test. A significant improvement in the InsI test scores following training was observed for the CIA-T1 group. No significant improvement was observed for both HA-T1 and CIC-T1 groups. The HA-T2 and CIA-T2 participants showed a statistically significant post-training improvement. The CIC-T2 group also showed some improvement in the InsI test scores following training but the change was not statistically significant.

The HA-T1 participants failed to show a significant improvement in the InsI test following training; however, the HA-T2 participants showed a significant improvement in the InsI test. Two possible explanations can be provided for this finding. Firstly, when the musical background data was compared between the HA-T1 and HA-T2 groups, it was revealed that the frequency of actively taking part in music-related activities after receiving their HAs are higher for the HA-T2 group compared to the HA-T1 group. Woods and

Yund (2007) reported that the tonotopic maps in the auditory cortex undergo changes as a consequence of the SNHL. Active participation in listening activities would help reorganize the tonotopic cortical maps and is thus required to help the hearing impaired to gain the maximum benefit from amplification (Woods & Yund, 2007). Hence, it is proposed that active participation in music related activities after receiving hearing aids could have also helped the HA-T2 group to gain the maximum benefit from the training. In addition, when the scores obtained by the HA-T1 group for the InsI test were carefully examined, it was revealed that they obtained a 12.51% improvement after training. Their scores were close to the post-training scores obtained by the NHA group for the InsI test. Therefore, it is postulated that the pitch-perception training helped improve the InsI abilities of the HA-T1. However, as they almost reached the ceiling score that could be obtained for the InsI test, the percentage of improvement was not sufficient to bring about a significant finding.

The significant improvement observed in the CIA-T1 and CIA-T2 groups are in agreement with past research which states that adult CIA recipients benefit from timbre training (Gfeller et al., 2002b; Gfeller et al., 1998b; Gfeller., 1997). Gfeller at al. (2002b) tested 51 adult CI recipients and 20 NH adults on an instrument identification test that contained eight instruments representing four instrumental families and three frequency ranges. Participants in the training group were significantly better at identifying musical instruments than the control participants. Additionally, there was a significant improvement in the number of instruments identified during the post-training compared to pre-training testing. For the overall quality rating, the training group showed a significant improvement in the post-training scores, which was not observed in the normal control group (Gfeller et al., 2002b).

In this study, the CIC participants trained with either version of the training program failed to show any significant improvement in the InsI test. High variability in the present results and the small sample size used in this study could have affected the statistical power of the results obtained from the CIC training participants in both versions. Furthermore, the CIC participants trained with V2T did not complete the entire training program as prescribed. Therefore, it is difficult to come to a conclusion as to whether CIC benefitted from training on this particular task.

Pitch Ranking (PR)

Although none of the participants trained with V1T showed a significant improvement in the post-training PR scores, the CIA and HA groups trained with V2T showed a significant improvement on the PR test scores. Therefore, Hypothesis Three is rejected and Hyptothesis Four is partially accepted.

The difference in the performance between V1T and V2T, as observed in the CIA and HA groups, could be explained in relation to differences between the two versions of the training program. Amitay et al. (2006b) reported that auditory training facilitates the ability to attend to a task-specific stimulus dimension and to access acoustic information at the peripheral level so that the acoustic information is available for further processing of the signal. Neural studies that correlate the perceptual judgment of frequency discrimination confirm that the extent of changes in the cortical area corresponding to the frequency change of an auditory input parallels the performance of the frequency discrimination abilities of the adult primates (Recanzone, Schreiner, & Merzenich, 1993).

In Recanzon et al.'s (1993) study, five adult owl monkeys were trained to discriminate small differences in frequency of sequentially presented tones. The results obtained from the behavioural measures were parallel to that of the changes observed in the auditory cortical areas through electrophysiological measures. These results provide further evidence for the plasticity of the auditory cortex, which is reflected in the acquisition of the auditory skills (Recanzone et al., 1993). In addition, Liu et al. (2008) reported that training through a transition from easier to harder tasks improves auditory perceptual learning. It is proposed that the adaptive training protocols and the gradual transition of easy-to-difficult tasks used in V2T could have facilitated the significantly better results observed in both CIA and HA groups trained with V2T compared to those trained with V1T.

5.2 Hypotheses Five

Hypothesis 5: *The overall training improvement will be higher for the V2T groups than the V1T groups.*

Hypothesis Five was partially accepted as the CIA and HA participants trained with V2T showed a significant improvement following training in more tests than those trained with V1T. However, no such pattern was found for the CIC participants. With a total of 13 post-training tests, the CIA participants trained with V1T showed a significant improvement in two of the tests (InsI and EI-Both tests) while those trained with V2T showed a significant improvement in six tests (FMI-Rh, FMI-NoRh, InsI, EI-Female, EI-Both, and Q/S-Both tests) following training. The HA participants trained with V1T showed a significant post-training improvement in five tests (CNC-Ph, EI-Male, EI-Female, EI-Both, and Q/S-Female tests) while those trained with V2T showed a significant improvement in six tests (FMI-NoRh, InsI, EI-Female, EI-Both, Q/S-Male, and Q/S-Both tests). The CIC participants did not show any training effect with either V1T or V2T.

Objective tests are important in evaluating the efficacy of a rehabilitation program; however, no evaluation would be complete without subjective evaluations (Gfeller et al., 2000a). Information obtained from the post-training evaluation questionnaires revealed that the HA group trained with V2T believed that the present pitch-perception training program helped improve their skills in performing the majority of pitch-related speech and music tasks while those trained with V1T remained neutral. The CIA group trained with either V1T or V2T generally agreed that they perceived an improvement in performing pitch-related speech and music perception tasks after training. The CIC group trained with either version of the program and their parents generally agreed that they did not notice any change in their skills in performing pitch-related speech and music perception tasks after completing training. The subjective observations seem to be consistent with the objective post-training test results.

It is assumed that the differences observed between V1T and V2T groups were basically due to the differences in the two versions of the training program. The V1T program differed from the V2T program in a number of ways. Firstly, V1T program provided training at a constant semitone separation level while V2T program used an adaptive training procedure. Secondly, V1T started all the tasks with a separation of 12 semitones between the highest and lowest notes presented in each trial and did not provide intensive training at the 1 to 6 semitone separation levels. Although V2T also started all tasks at the 12 semitone separation level, it gradually descended to a one semitone separation level at a rate depending on a trainee's performance in each separation level, providing an easy-to-difficult graduated progression in training.

Adaptive training programs start with stimuli that are easily detectable or discriminable and then gradually proceed to make the task more difficult (Moore et al., 2005). Amitay et al. (2006b) reported that an improvement in performance was observed when the difficulty level of a task was increased from easy to difficult. The training was most effective if the training task was neither too easy nor too difficult as it had to be challenging enough to generate the interest of the trainees but not too hard to ensure their motivation (Amitay et al., 2006b; Moore & Amitay, 2007). Feedback received from the participants trained with V1T was that the tasks were too easy and not challenging enough to keep their attention for a long period of time. In contrast, the participants trained with V2T reported that as the tasks became more difficult, they had to concentrate before they selected their responses on the computer screen. In some cases, they had to use the 'play again' button and listen to the sounds many times before deciding on the correct answer. It has been found that adult CI recipients required an F0 difference of more than three semitones to discriminate two notes while adult hearing aid users with a similar degree of hearing loss could perform above chance level at the three semitone separation level (Looi et al., 2008c). The tasks in V1T, which provided stimuli at a constant 12 semitone separation level, may not be challenging enough for either CI recipients or hearing aid users.

There are few studies demonstrating that adaptive training is better than fixed- level training (Stacey et al, 2010). Amitay et al. (2006b) carried out a study in which adaptive and fixed-level trainings were compared. In the adaptive training, frequency difference between the standard (1kHz) and the comparison tone was varied adaptively to obtain 95%, 75%, and 50% correct response levels. In the fixed-level training, the frequency difference was kept constant at 1 Hz, 7 Hz, and 400 Hz. A paradigm employing three interval sizes and a three alternative forced choice was used to present stimuli during training. Subjects were asked to pick up the odd one out of the three tones they heard. Results revealed that all three adaptive training paradigm showed significant training effect ($p < 0.001$), but no significant difference was seen among three training groups. Results obtained from the fixed-level training groups revealed that hen the task was made easy, by keeping the frequency difference between the standard and the test tone at a constant 400 Hz separation, it produced only a small improvement ($p = 0.036$) in participants' scores. However, when the task was made more difficult, by reducing the frequency difference between the test and standard tones to 7 Hz or further down to 0 Hz, it produced a strong ($p < 0.001$) learning effect similar to the ones obtained by the participants who completed the adaptive training (Amitay et al., 2006b). These results agree with our current finding that both HA and CIA groups obtained less benefit from training when trained with V1T than when trained with V2T. In the V1T program, the tasks were made easy by keeping the F0 distance between tones wide apart. In contrast, when the tasks were made difficult as in V2T, which gradually reduced the separation levels and thus increased the difficulty level using an adaptive protocol, more substantial improvements in post-training test scores were observed.

The results observed in the current study could also be related to the trainee's attention and active engagement in tasks. Based on the post-training questionnaires, participants trained with V1T reported that as the tasks were easy, they could easily carry out tasks without having to pay much attention. It is noteworthy that the majority of V1T participants completed most of their training within the 12 to 6 semitone difficulty levels. Hence, it is not surprising that they reported the tasks were too easy. Participants trained with V2T reportedly found the tasks to be challenging and had to focus their attention and actively engage in the training tasks throughout the training session. Since auditory learning largely depends on attention and arousal, active engagement induced by challenging tasks result in strong learning effects (Moore & Amitay, 2007). During performance of attention-demanding cognitive tasks, certain regions of the brain routinely increase activity (Fox et al., 2005). Focused attention has been defined as the ability to respond to a discrete stimulus, whereas selective attention is the ability to maintain a behavioral or cognitive set in the face of distracting or competing stimuli (McKay & Mateer, 1989). Tasks used in the current training program required both selective and focused attention of the participants. Woldorff et al. (1993) reported that focused auditory attention influenced the early auditory cortical processing 20 msec immediately following the onset of a stimulus. Evidence obtained from event-related-potential and event-related magnetic field studies has demonstrated changes in auditory cortical activities when subjects were selectively attending to changes of pitch (Sussman et al., 2002) and intensity (Woldorff et al., 1993, 1998) in a given stimuli. This supports a top-down process which affects the perception of sounds at a very early stage (Sussman et al., 2002). Hence, it is assumed that the improvements observed in participants trained with V2T compared to those trained with V1T could be due to the use of an adaptive training paradigm in V2T. The V2T program provided tasks proceeding from easy to gradually difficult in a more individualized manner, which may in turn have resulted in more active engagement, focus, and selective attention for the trainees.

5.4 Limitations of the Study

There are limitations to be noted regarding the present study. The main limitation concerns the limited number of participants involved in the study, especially the CIC participants, due to the unexpected recruitment issues which were beyond the researcher's control. There were only five CIC participants, with three trained with V1T and two with V2T. More CIC participants are needed to help draw inferences from the observed results. Additionally, based on the data logging information, it appears that the CIC participants who underwent V2T did not complete the entire training program. Hence, it was difficult to draw any conclusions as to whether the CIC participants had received the full benefit from the adaptive pitch-perception training. A more vigorous monitoring strategy and a more effective motivation scheme are needed to ensure that participants adhere to the training regimen.

In both versions of the training program, participants had the flexibility in selecting the instruments or sung vowels that they wanted to practice. Allowing participants to self-select instruments might have generated some amount of enthusiasm in the participants and also allowed them to adjust their training to their needs and preferences. However, this flexibility may be less suited for a research study in that it prevents a tight control over the types of instruments and tasks that participants train on. Some of the V1T participants did not complete training on certain instruments and one participant trained only on the pitch ranking task. As this training program is currently at the 'pilot test' stage, this flexibility was allowed. Furthermore, this program was designed for use in real-world, clinical application for CI recipients and hearing aid users rather than for research purposes only. In the future, a greater control over the training may be needed to optimize the training effect.

The training prescription also needs to be modified for better group comparisons. In the present study, participants were asked to train for 10 minutes on each of the three training tasks. This introduced a considerable amount of variability in the number of stimuli participants trained with during training. Some participants trained for more than the requested time frame while others trained less than they were supposed to. Some participants attended to many training stimuli, others did less so. For example, it was observed from the data logging information that some participants trained with about 15 stimuli while some attended to more than 100 stimuli. This variability may weaken the subject equivalency between the comparison groups. If participants had been asked to train with a preset number of stimuli per task per session, both V1T and V2T groups could have attended to a more equivalent amount of training to allow for a better comparison.

Another drawback was that V1T participants could not complete sufficient training across all semitone levels during the given timeframe. The V1T program was designed to deliver a constant number of training stimuli at each semitone separation level. For each type of instrument and task, the program delivered training stimuli starting from the 12 semitone separation level and descending to the one semitone separation level. As participants were asked to spend only 10 minutes on each task, most of the participants could not proceed beyond the 10 semitone separation level within this timeframe. Consequently, most of the participants could not complete training across all semitone separation levels. Delivery of a constant number of training stimuli per instrument for each semitone separation level would have eliminated this constraint.

The comparison of training effect between the two versions of the training program is exploratory in this study. While the effect of V1T was investigated with both a pre- and post-training comparison and a training-control group comparison, V2T involved only a pre- and post-training comparison within the training group (see Figure 2). Use of a balanced group design for both versions of the training program would have been ideal. Unfortunately, the time constraint for subject recruitment prohibited this.

Another consideration relates to the high variability among participants within each of the hearing impaired groups. In the CIA group, five participants were using bi-modal stimulation, one CIA participant using both bimodal and hybrid EAS strategy, three CIA participants using the fine-structure speech processing strategy, and two using a limited number of channels. In the HA group, there was a wide range of hearing loss and a large variety of hearing aids used. With a larger sample, the heterogeneity within each group would have enhanced the ability of the present findings to generalize. However, with a small sample size as in the present study, variations due to the extraneous factors are hard to account for.

Participants in the V2T groups attended pre-training test 1, pre-training test 2 (as the controls for V1T) before undergoing the V2T, and post-training test 2 after completing the V2T. Hence, compared to V1T groups, the V2T groups attended assessments three times. More familiarity with the assessments could have contributed to the improved post-training scores observed in the V2T groups following training.

Another limitation in both versions of the training program was that every time a participant started a new session of training with a new instrument, the program automatically selected stimuli from the 12-semitone level. The program did not have a memory feature to record the final difficulty level that participants were at upon the termination of a session. Had the program started delivering stimuli from the same difficulty level that participants had reached at the end of the previous session rather than starting from the 12-semitone level, some amount of training time could have been saved and the fatigue of the trainees could have been reduced. Additionally, as participants spent the first few minutes starting their training from the 12-semitone level before progressing to the next difficulty levels, this could have prevented them from reaching the lower (more difficult) semitone levels within the given 10 minutes of timeframe.

Subject equivalency between the control and training groups is another concern. The age, gender, and hearing devices used were not uniform between the training and control groups in the CIA, CIC, and HA groups. Age-related factors, such as memory, cognition, reaction time, and efficiency in performing tasks, may have impacted on the test scores. It would have been ideal to match the training and control groups on certain variables such as age, experience with CI, music experience. However, this was not practical due to the limited number of CI recipients in New Zealand. In addition, the hearing levels between the HA and CI participants prior to receiving their hearing aid or the CI were different. The aim of the current study was to investigate whether each individual participant group benefits from pitch perception training, hence, this difference was not considered as a major drawback. However, this could have affected some of the comparisons made between HA and CI groups.

The study design used with the V2T participants is another drawback of this study. It would have been ideal to use the A1-A2-B study design with the V2T participants where A1-pre-training testing, A2- post-training testing1 and B-post-training testing 2. The difference between A1 and A2 could have been used as the baseline and the difference with the A2 and B would have demonstrated the improvement made as a result of the V2T. However, this method could not be implemented with the V2T participants as the difference between A1 and A2 were high for most of the tests that were used in this study. In ideal circumstances, there would not be any difference between A1 and A2 test results as the V2T participants did not receive any training between A1 and A2 conditions. This observed difference in test scores could have been a result of incidental learning, increased familiarity with the test protocols and the steps taken by the participants to increase the amount of time spent on music related activities. Therefore, an A1-A2-B design was not implemented with the V2T participants.

Another limitation of this study is inclusion of bimodal and hybrid users within the cochlear implant group. The aim of the study was to evaluate the effects of pitch-perception training on hearing impaired individuals with their everyday sensory device, rather than evaluating the effects of pitch-perception training on hearing impaired individuals based on type of stimulation used. Hence, measures were not taken to separately evaluate the effects of pitch-perception training on pitch related aspects of speech and music skills of CI-only, bimodal and hybrid users. However, as both bimodal and hybrid users have more access to low frequency fine structure information through the use of a hearing aid in addition to the CI, their results could have skewed the results of the cochlear implant group as a whole.

Lastly, the HA participants in the training groups exhibited a ceiling effect in the pre-training familiar melody identification test scores. Thus, it was difficult to evaluate whether the training program could help hearing aid users to improve their familiar melody identification skills.

5.5 Future Directions

On the basis of the results obtained in this project, a number of further research directions are proposed. These include:

1. Most of the participants who underwent training reported that 10 weeks of training was long. More than half of the CIA and HA participants remained neutral on their views about having a 30-minute training session and 4 sessions per week. It was also observed that participants trained with V2T spent an average of only 15 hours on training in 10 weeks. However, these participants showed better improvement than participants trained with V1T, despite the fact that the V1T participants spent more hours on training than the V2T participants. These findings suggest that it would be appropriate to design an eight-week training program consisting of 30 minutes per session, four sessions per week.
2. The majority of the training participants commented that a summary of results per session would have been motivating. Thus, the training program needs to be modified to provide a visual output (e.g., graphs) that indicates the overall performance across different instruments and training sessions.

3. Adult participants were not concerned about the reinforcement pictures used in the training program. They reported that their only concern was how well they performed each task. In addition, they wanted the training program to be more challenging. Both versions of the current training program could be made more challenging by increasing the number of response choices (e.g., foils) in the pitch contour task. Informal correspondence from trainees indicated requests to incorporate a module containing an emotion identification task, Q/S identification task, familiar melody identification task, and instrument identification tasks into the current training program to help generalize learnt pitch skills to daily life situations. Therefore, it would be useful to include other modules containing the above mentioned tasks in a training program to make it more relevant to the trainee’s daily listening tasks.
4. In contrast to the suggestions given by both groups of adult CIA and HA participants, all CIC participants viewed the training program as somewhat boring. They were reluctant to take part in the training sessions as the training sessions were not entertaining. They requested a variety of reinforcements, such as pop-ups, funny cartoons, and inclusion of the latest pop songs in order to make the program more interesting. The CIC participants paid more attention to the appearance of the program than the content. However, it is clear that even if the same content is used with both adult and teenage participants, the appearance of the training program used by the teenagers needs to be changed considerably to make it more engaging and relevant for them.

5. The current training program is compatible with Windows platforms; therefore, training for participants using Mac computers was not possible. The V2T program needs to be modified to be used in both Windows and Mac computers. Another suggestion would be to make it accessible via the internet or multimedia-enabled smart phones. The current training program could also be improved using intelligent tutoring system techniques (i.e., a computer program that provides direct customized training and feedback to the users) to deliver stimuli that are tailor-made for each participant's requirements. Both groups of adult participants were happy completing training using their home computers; however, teenage CIC participants were not that interested in completing training using a home computer. They mentioned that if the hardware of the training program was designed to be similar to an iPod with direct audio input that could be connected to their speech processor, they could carry out training easily while travelling in a bus or in a comfortable place. They mentioned that such a training program would be "very cool". This is a very interesting suggestion as rehabilitation programs need to be designed to suit the needs of different age groups.
6. Past research and findings from this study suggest that adult CI recipients using bimodal stimulation perform better in pitch-related tasks than those who used a CI only. It would be useful to compare the effect of pitch perception training on the speech and music perception between the CI-only recipients and the CI recipients using bimodal stimulation in both prelingually deafened and postlingually deafened CI recipients.

7. Finally, as pitch is more linguistically relevant in tonal languages than non-tonal languages and tonal language speech perception remains a challenge to many CI participants, further investigations regarding the effect of pitch perception training on the speech perception of tonal language speakers with hearing impairment are needed. The V1T program is currently being pilot tested on nine Cantonese speaking adult postlingually deafened CIA participants. It is important to expand the scope of the investigation and further evaluate the effect of pitch-perception training on the speech and music perception skills of prelingually deafened tonal language speaking CIC participants and assess the relationship between pitch, music, and lexical tone perception.

5.6 Clinical Implications

This study has provided evidence in support of the use of pitch perception training for improving the skills of the hearing impaired in performing a selection of pitch-related speech and music perception tasks. Some preliminary evidence was also provided in support of the use of an adaptive training approach. The computerized pitch-perception training program developed in this study was designed as a habilitation/rehabilitation tool to be used in clinical settings with both CI recipients and hearing aid users to improve their pitch-related speech and music perception skills. This program could be used in clinical settings and could also be given for use at home. The data logging feature in the program will allow the clinician to get more insights into the number of hours spent on training, performance across semitone levels, and scores obtained for each task. This program could also be used in a long-term, ongoing manner, which might be appealing to CI recipients and hearing aid users, rather than as a short intensive training program with specific timings.

5.7 Summary and Conclusions

Overall, the two NH groups scored the highest and the HA group performed better than both CIA and CIC groups in the majority of the baseline pre-training measurements. Amongst all three groups trained with V1T, the HA group showed the most improvement and the CIC group the least. Binaural advantage and the ability to take advantage of low frequency residual hearing, and better hearing abilities compared to the CI recipients (i.e., the majority of the HA group have mild to moderately-severe hearing loss compared to the moderately-severe to profound SNHL of the CI recipients) could have helped the HA group to improve their pitch-related speech and music perception skills through pitch-perception training more than the CIA group. The lower training effect observed in both versions of the training program for the CIC participants trained with V1T could have been due to the technical limitations of the CI device, the lack of an understanding of the concept of identifying emotions and Q/S through auditory cues alone, the limited or no experience of the CIC participants in listening to sounds through acoustic hearing, and the use of a fixed level of training with less challenging tasks. Among all three groups that underwent V2T, the CIA group performed the best in the majority of the post-training tests, closely followed by the HA group. Despite the technical limitations of the CI device, it is proposed that the use of an adaptive training paradigm and challenging tasks in training as in V2T program could help adult CI recipients to improve their pitch-related speech and music perception skills.

In conclusion, pitch-perception training using an adaptive training paradigm that gradually introduced easy to difficult tasks improved pitch-related perception in both postlingually deafened adult CI recipients and hearing aid users. Some generalization of the learning acquired through the pitch perception training to the performance in a selection of pitch-related speech and music perception tasks was observed. More challenging training tasks, which required more focused attention, appeared to provide better training than easy tasks. The development of the two versions of the pitch perception training program examined in this study represents the first step at attempting to improve the pitch-related speech and music perception skills of hearing impaired children and adults. The proposed training program provides a habilitative/rehabilitative approach that can be offered to new and current CI recipients as a speech processing strategy that will significantly improve music perception is still some way off with current technology and new technology may also be applicable only to new recipients. Of the two versions, the V2T was found to provide better training outcomes; therefore, based on results and feedback obtained from V2T, changes are being made to finalize the program.

References

Abdi, S., Khalessi, M. H., Khorsandi, M., & Gholami, B. (2001). Introducing music as a means of habilitation for children with cochlear implants. *International Journal of Pediatric Otorhinolaryngoly, 59*(2), 105-113.

Alcántara, J. I., Moore, B. C. J., Kühnel, V., & Launer, S. (2003). Evaluation of the noise reduction system in a commercial digital hearing aid. *International Journal of Audiology, 42*(1), 34-42.

Amitay, S., Irwin, A., & Moore, D. R. (2006b). Discrimination learning induced by training with identical stimuli. *Nature Neuroscience, 9*(11), 1446-1448.

Andrews, M. L., & Madeira, S. S. (1977). The Assessment of Pitch Discrimination Ability in Young Children. *Journal of Speech and Hearing Disorders, 42*(2), 279-286.

American National Standards Institute (ANSI) (1994). *American National Standard Acoustical Terminology.* New York: American National Standards Institute.

American Standards Association (ASA) (1960). *Acoustical Terminology SI, 1-1960*. New York: American Standards Association.

Arehart, K. H. (1994). Effects of harmonic content on complex-tone fundamental-frequency discrimination in hearing-impaired listeners. *Journal of the Acoustical Society of America, 95*(6), 3574-3585.

Bachorowski, J. A., & Owren, M. J. (2003). Sounds of Emotion: Production and Perception of Affect-Related Vocal Acoustics. *Annals of the New York Academy of Sciences, 1000*, 244-265.

Baer, T., & Moore, B. C. J. (1994). Effects of spectral smearing on the intelligibility of sentences in the presence of interfering speech. *The Journal of the Acoustical Society of America, 95*(4), 2277-2280.

Banse, R., & Scherer, K. R. (1996). Acoustic Profiles in Vocal Emotion Expression. *Journal of Personality and Social Psychology, 70*(3), 614-636.

Battmer, R. D., Dillier, N., Lai, W. K., Begall, K., Leypon, E. E., Gonzalez, J. C., et al. (2010). Speech perception performance as a function of stimulus pulse rate and processing strategy preference for the Cochlear Nucleus CI24RE device: relation to perceptual threshold and loudness comfort profiles. *International Journal of Audiology, 49*(9), 657-666.

Bentler, R. A., Palmer, C., & Dittberner, A. B. (2004). Hearing-in-Noise: Comparison of Listeners with Normal and (Aided) Impaired Hearing. *Journal of the American Academy of Audiology, 15*(3), 216-225.

Bernstein, J. G., & Oxenham, A. J. (2003). Pitch discrimination of diotic and dichotic tone complexes: Harmonic resolvability or harmonic number? . *Journal of the Acoustical Society of America, 113*(6), 3323-3334.

Bernstein, J. G. W., & Oxenham, A. J. (2006). The relationship between frequency selectivity and pitch discrimination: Sensorineural hearing loss. *The Journal of the Acoustical Society of America, 120*(6), 3929-3945.

Besson, M., Schon, D., Moreno, S., Santos, A., & Magne, C. (2007). Influence of musical expertise and musical training on pitch processing in music and language. *Restorative Neurology and Neuroscience, 25*(3-4), 399-410.

Blamey, P. J., Fiket, H. J., & Steele, B. R. (2006). Improving speech intelligibility in background noise with an adaptive directional microphone. *Journal of the American Academy of Audiology, 17*(7), 519-530.

Blumberg, M., Stilings, N., Couperus, J., & Goldsworthy, R. (2006). Music as a rehabilitation tool for cochlear implant users. [On-line]. Retrieved 11 October 2011: Available: https://dspace hampshire.edu

Boothroyd, A., Hanin, L., & Hnath, T. (1985). A sentence test of speech perception: Reliability, set equivalence, and short term learning. *Speech and Hearing Science Report RC10.*

Boyd, R. C., Knutson, J. F., & Dahlstrom, A. J. (2000). Social interaction of pediatric cochlear implant recipients with age-matched peers. *Annals of Otology, Rhinology and Laryngology Supplement, 185*, 105-109.

Busby, P. A., Whitford, L. A., Blamey, P. J., Richardson, L. M., & Clark, G. M. (1994). Pitch perception for different modes of stimulation using the cochlear multiple-electrode prosthesis. *Journal of the Acoustical Society of America, 95*(5 Pt 1), 2658-2669.

Carral, V., Huotilainen, M., Ruusuvirta, T., Fellman, V., Näätänen, R., & Escera, C. (2005). A kind of auditory 'primitive intelligence' already present at birth. *European Journal of Neuroscience, 21*(11), 3201-3204.

Chang, W. H., Tseng, H. C., Chao, T. K., Hsu, C. J., & Liu, T. C. (2008). Measurement of hearing aid outcome in the elderly: Comparison between young and old elderly. *Otolaryngology-Head and Neck Surgery, 138*(6), 730-734.

Chasin, M. (2007). Music as an input to a hearing aid. *Audiology Online*. Retrieved from http://www.audiologyonline.com/articles/article_detail.asp?article_id=1759

Chasin, M., & Russo, F. A. (2004). Hearing Aids and Music. *Trends In Amplification, 8*(2), 35-47.

Ching, T., Dillon, H., & Byrne, D. (1998). Speech recognition of hearing-impaired listeners: Predictions from audibility and the limited role of high-frequency amplification. *Journal of the Acoustical Society of America, 103*(2), 1128-1140.

Ching, T., Incerti, P., Hill, M., & van Wanrooy, E. (2006). An overview of binaural advantages for children and adults who use binaural/bimodal hearing devices. *Audiology and Neurotology, 11*(Suppl 1), 6-11.

Ching, T. Y. C. (2005). The evidence calls for making binaural-bimodal fittings routine. *Hearing Journal, 58*(11), 32-41.

Ching, T. Y. C., Incerti, P., & Hill, M. (2004b). Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. *Ear and Hearing, 25*(1), 9-21.

Ching, T. Y. C., Psarros, C. E., Hill, M., Dillon, H., & Incerti, P. (2001). Should children who use cochlear implants wear hearing aids in the opposite ear? *Ear and Hearing, 22*(5), 365-380.

Chung, K. (2004a). Challenges and Recent Developments in Hearing Aids. *Trends in Amplification, 8*(4), 125-164.

Ciocca, V., Francis, A. L., Aisha, R., & Wong, L. (2002). The perception of Cantonese lexical tones by early-deafened cochlear implantees. *Journal of the Acoustical Society of America, 111*(5 Pt 1), 2250-2256.

Cullington, H. E., & Zeng, F.-G. (2008). Speech recognition with varying numbers and types of competing talkers by normal-hearing, cochlear-implant, and implant simulation subjects *Journal of the Acoustical Society of America, 123*(1), 450-461.

Davis, A. C. (1989). The Prevalence of Hearing Impairment and Reported Hearing Disability among Adults in Great Britain. *International Journal of Empidemiology, 18*(4), 911-917.

Davis, M. H., & Johnsrude, I. S. (2007). Hearing speech sounds: Top-down influences on the interface between audition and speech perception. *Hearing Research, 229*(1-2), 132-147.

Dawson, P. W., Blamey, P. J., Rowland, L. C., Dettman, S. J., Clark, G. M., Busby, P. A., et al. (1992). Cochlear implants in children, adolescents, and prelinguistically deafened adults: speech perception. *Journal of Speech and Hearing Research, 35,* 401–417.

Dillon, H. (2001). *Hearing Aids*. Sydney: Boomerang Press.

Dorman, M. F., Basham, K., McCandless, G., & Dove, H. (1991). Speech understanding and music appreciation with the Ineraid cochlear implant. *The Hearing Journal, 44,* 34-37.

Dorman, M. F., Gifford, R. H., Spahr, A. J., & McKarns, S. A. (2008). The Benefits of Combining Acoustic and Electric Stimulation for the Recognition of Speech, Voice and Melodies. *Audiology and Neurotology, 13*(2), 105-105-112.

Dowell, R. C., Blamey, P. J., & Clark, G. M. C. (1995). Potential and limitations of cochlear implants in children *Annals of Otology, Rhinology and Laryngology, 104* (Part 2, Suppl. 166), 324–327.

Dowling, W. J. (1999). The development of music perception and cognition. In D. Deutsche (Ed.), *The Psychology of Music* (pp. 603-624). San Diego, CA: Academic Press.

Dowling, W. J., & Bartlett, J. C. (1981). The importance of interval information in longterm memory for melodies. *Psychomusicology, 1,* 30-49.

Dunn, J., Bretherton, I., & Munn, P. (1987). Conversations About Feeling States Between Mothers and Their Young Children. *Developmental Psychology, 23*(1), 132-139.

Dunn, J., Brown, J., & Beardsall, L. (1991). Family Talk About Feeling States and Children's Later Understanding of Others' Emotions. *Developmental Psychology, 27*(3), 448-455.

Dyck, M. J., Farrugia, C., Shochet, I. M., & Holmes-Brown, M. (2004). Emotion recognition/understanding ability in hearing or vision-impaired children: do sounds, sights, or words make the difference? *Journal of Child Psychology and Psychiatry, 45*(4), 789-800.

Eddington, D. K. (1980). Speech discrimination in deaf subjects with cochlear implants. *Journal of the Acoustical Society of America, 68*(3), 885-891.

Eggermont, J. J., Ponton, C. W., Don, M., Waring, M. D., & Kwong, B. (1997). Maturational Delays in Cortical Evoked Potentials in Cochlear Implant Users. *Acta Oto-laryngologica, 117*(2), 161-163.

Engen, T., Engen, E. A., Clarkson, R. L., & Blackwell, P. M. (1983). Discrimination of intonation by hearing-impaired children. *Applied Psycholinguistics, 4*(02), 149-160.

Fetterman, B. L., & Domico, E. H. (2002). Speech recognition in background noise of cochlear implant patients. *Otolaryngology-Head and Neck Surgery, 126*(3), 257-263.

Florentine, M. (1988). Temporal integration in normal hearing, cochlear impairment, and impairment simulated by masking. *Journal of the Acoustical Society of America, 84*(1), 195-203.

Fox, M. D., Snyder, A. Z., Vincent, J. L., Corbetta, M., Van Essen, D. C., & Raichle, M. E. (2005). The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proceedings of the National Academy of Sciences of the United States of America, 102*(27), 9673-9678.

Franks, J. R. (1982). Judgments of hearing aid processed music. *Ear and Hearing, 3*(1), 18-23.

Friedman, M. (1985). Remediation of intonation contours of hearing-impaired students. *Journal of Communication Disorders, 18*(4), 259-272.

Friesen, L. M., Shannon, R. V., Baskent, D., & Wang, X. (2001). Speech recognition in noise as a function of the number of spectral channels: Comparison of acoustic hearing and cochlear implants. *The Journal of the Acoustical Society of America, 110*(2), 1150-1163.

Fryauf-Bertschy, H., Tyler, R. S., Kelsay, D. M. R., Gantz, B. J., & Woodworth, G. G. (1997). Cochlear implant use by prelingually deafened children: the influences of age at implant and length of device use. *Journal of Speech, Language and Hearing Research, 40*(1), 183-199.

Fu, Q.-J., Galvin III, J., Wang, X., & Nogaki, G. (2005a). Moderate auditory training can improve speech performance of adult cochlear implant patients. *Acoustics Research Letters Online, 6*(3), 106-111.

Fu, Q.-J., & Galvin III, J. J. (2007b). Computer-Assisted Speech Training for Cochlear Implant Patients: Feasibility, Outcomes, and Future Directions. *Seminars in Hearing, 28*(02), 142-150.

Fu, Q.-J., Hsu, C.-J., & Horng, M.-J. (2004b). Effects of Speech Processing Strategy on Chinese Tone Recognition by Nucleus-24 Cochlear Implant Users. *Ear and Hearing, 25*(5), 501-508.

Fu, Q.-J., Nogaki, G., & Galvin III, J. (2005b). Auditory training with spectrally shifted speech: implications for cochlear implant patient auditory rehabilitation. *Journal of the Association for Research in Otolaryngology, 6*(2), 180-189.

Fu, Q.-J., Shannon, R. V., & Wang, X. (1998b). Effects of noise and spectral resolution on vowel and consonant recognition: Acoustic and electric hearing. *The Journal of the Acoustical Society of America, 104*(6), 3586-3596.

Fu, Q.-J., Zeng, F.-G., Shannon, R. V., & Soli, D. S. (1998a). Importance of tonal envelope cues in Chinese speech recognition. *The Journal of Acoustical Society of America 104*, 505-510.

Fu, Q. J., Chinchilla, S., Nogaki, G., & Galvin, J. J., 3rd (2005c). Voice gender identification by cochlear implant users: the role of spectral and temporal resolution. *Journal of the Acoustical Society of America, 118*(3 Pt 1), 1711-1718.

Fu, Q. J., Galvin, J., Wang, X., & Nogaki, G. (2004a). Effects of auditory training on adult cochlear implant patients: a preliminary report. *Cochlear Implants International, 5*(S 1), 84-90.

Fu, Q. J., & Galvin, J. J., 3rd (2007a). Perceptual learning and auditory training in cochlear implant recipients. *Trends in Amplification, 11*(3), 193-205.

Fujita, S., & Ito, J. (1999). Ability of nucleus cochlear implantees to recognize music. *Annals of Otology Rhinology and Laryngology, 108*(7), 634-640.

Gabrielsson, A., Schenkman, B. N., & Hagerman, B. (1988). The effects of different frequency responses on sound quality judgments and speech intelligibility by content. *Journal of Speech and Hearing Research, 31*(2), 166-177.

Galvin III, J. J., Fu, Q.-J., & Nogaki, G. (2007). Melodic Contour Identification in Cochlear Implant Users. *Ear and Hearing, 28*(3), 302-319.

Gfeller, K. (1998c). Music appreciation, from the perspective of implant recipients. *Contact, 12*, 24-25.

Gfeller, K. (2001). Aural Rehabilitation of Music Listening for Adult Cochlear Implant Recipients: Addressing Learner Characteristics. *Music Therapy Perspectives, 19*, 88-95.

Gfeller, K., Christ, A., Knutson, J., Witt, S., & Mehr, M. (2003). The effects of familiarity and complexity on appraisal of complex songs by cochlear implant recipients and normal hearing adults. *Journal of Music Therapy, 40*(2), 78-112.

Gfeller, K., Christ, A., Knutson, J. F., Witt, S., Murray, K. T., & Tyler, R. S. (2000b). Musical backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. *Journal of the American Academy of Audiology, 11*(7), 390-406.

Gfeller, K., Jiang, D., Oleson, J. J., Driscoll, V., & Knutson, J. F. (2010). Temporal stability of music perception and appraisal scores of adult cochlear implant recipients. *Journal of the American Academy of Audiology, 21*(1), 28-34.

Gfeller, K., Knutson, J. F., Woodworth, G., Witt, S., & De Bus, B. (1998b). Timbral recognition and appraisal by adult cochlear implant users and normal-hearing adults. *Journal of the American Academy of Audiology, 9*(1), 1-19.

Gfeller, K., & Lansing, C. (1992). Musical Perception of Cochlear Implant Users as Measured by the Primary Measures of Music Audiation - an Item Analysis. *Journal of Music Therapy, 29*(1), 18-39.

Gfeller, K., & Lansing, C. R. (1991). Melodic, rhythmic, and timbral perception of adult cochlear implant users. *Journal of Speech and Hearing Research, 34*(4), 916-920.

Gfeller, K., Oleson, J., Knutson, J. F., Breheny, P., Driscoll, V., & Olszewski, C. (2008). Multivariate Predictors of Music perception and Appraisal by Adult Cochlear Implant Users. *Journal of American Academy of Audiology, 19*, 120-134.

Gfeller, K., Olszewski, C., Rychener, M., Sena, K., Knutson, J. F., Witt, S., et al. (2005). Recognition of "real-world" musical excerpts by cochlear implant recipients and normal-hearing adults. *Ear and Hearing, 26*(3), 237-250.

Gfeller, K., Turner, C., Mehr, M., Woodworth, G., Fearn, R., Knutson, J. F., et al. (2002a). Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults. *Cochlear Implants International, 3*(1), 29-53.

Gfeller, K., Turner, C., Oleson, J., Zhang, X. Y., Gantz, B., Froman, R., et al. (2007). Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise. *Ear and Hearing, 28*(3), 412-423.

Gfeller, K., Witt, S., Adamek, M., Mehr, M., Rogers, J., Stordahl, J., et al. (2002b). Effects of training on timbre recognition and appraisal by postlingually deafened cochlear implant recipients. *Journal of the American Academy of Audiology, 13*(3), 132-145.

Gfeller, K., Witt, S., Stordahl, J., Mehr, M., & Woodworth, G. (2000a). The Effects of Training on Melody Recognition and Appraisal by Adult Cochlear Implant Recipients. *Journal of the Academy of Rehabilitative Audiology, XXXIII*, 115-138.

Gfeller, K., Witt, S., Woodworth, G., Mehr, M. A., & Knutson, J. (2002c). Effects of frequency, instrumental family, and cochlear implant type on timbre recognition and appraisal. *Annals of Otology, Rhinology and Laryngology, 111*(4), 349-356.

Gfeller, K., Witt, S. A., Kim, K.-H., Adamek, M., & Coffman, D. (1999). Preliminary Report of a Computerized Music Training Program for Adult Cochlear Implant Recipients. *Journal of the Academy of Rehabilitative Audiology, 32*, 11-28.

Gfeller, K., Witt, S. A., Spencer, L. J., Stordahl, J., & Tomblin, B. (1998a). Musical involvement and enjoyment of children who use cochlear implants. *Volta Review, 100*(4), 213-233.

Gfeller, K., Woodworth, G., Robin, D. A., Witt, S., & Knutson, J. F. (1997). Perception of Rhythmic and Sequential Pitch Patterns by Normally Hearing Adults and Adult Cochlear Implant Users. *Ear and Hearing, 18*(3), 252-260.

Gilley, P. M., Sharma, A., & Dorman, M. F. (2008). Cortical reorganization in children with cochlear implants. *Brain Research, 1239*, 56-65.

Glasberg, B. R., & Moore, B. C. J. (1986). Auditory filter shapes in subjects with unilateraland bilateral cochlear impairments. The Journal of the Acoustical Society of America, 79(4), 1020-1033.

Grasmeder, M. L., & Lutman, M. E. (2006). The identification of musical instruments through Nucleus cochlear implants. *Cochlear Implants International: An Interdisciplinary Journal, 7*(3), 148-158.

Greville, A. (2005). *Hearing impaired and deaf people in New Zealand; an update.* Auckland: Greville Consulting Management of Hearing Services.

Gstoettner, W. K., Hamzavi, J., Egelierler, B., & D., B. W. (2000). Speech Perception Performance in Prelingually Deaf Children with Cochlear Implants. *Acta Otolaryngol, 120,* 209–213.

Haan, J., van Heuven, V. J., Jos, J. A., Pacilly, J. J. A., & van Bezooijen, R. L. (1997). An anatomy of Dutch question intonation. *Linguistics in the Netherlands*, 97-108.

Harrison, R. V., Gordon, K. A., & Mount, R. J. (2005). Is there a critical period for cochlear implantation in congenitally deaf children? Analyses of hearing and speech performance after implantation. *Developmental Psychobiology, 46*, 252-261.

He, C., Hotson, L., & Trainor, L. J. (2007). Mismatch responses to pitch changes in early infancy. *Journal of Cognitive Neuroscience, 19*(5), 878-892.

Henry, B. A., McKay, C. M., McDermott, H. J., & Clark, G. M. (2000). The relationship between speech perception and electrode discrimination in cochlear implantees. *Journal of the Acoustical Society of America, 108*(3 Pt 1), 1269-1280.

Henry, B. A., & Turner, C. W. (2003). The resolution of complex spectral patterns by cochlear implant and normal-hearing listeners. *Journal of the Acoustical Society of America, 113*(5), 2861-2873.

Hepper, P., & Shahidullah, S. (1994). Development of fetal hearing. *Archives of Disease in Childhood - Fetal and Neonatal Edition, 71*(2), F81-F87.

Holt, C. M., & J., F. (2010). *Pitch accentuation in adolescent users of cochlear implants.* Paper presented at the Thirteenth Australasian International Conference on Speech Science and Technology, Melbourne, Australia.

House, D. (1994). *Perception and Production of Mood in Speech by Cochlear Implant Users.* Paper presented at the 3rd International Conference on Spoken Language Processing (ICSLP 94), Yokohama, Japan.

House, D. (2004). *Pitch and alignment in the perception of tone and intonation: pragmatic signals and biological codes*. Paper presented at the International Symposium onTonal Aspects of Languages: With Emphasis on Tone Languages. Retrieved from www.isca-speech.org/archive/tal2004/tal4_093.html

Houtsma, A. J. M. (1997). Pitch and timbre: Definition, meaning and use. *Journal of New Music Research, 26*(2), 104-115

Houtsma, A. J. M., & Smurzynski, J. (1990). Pitch identification and discrimination for complex tones with many harmonics. *The Journal of the Acoustical Society of America, 87*(1), 304-310.

Howard, D. M., & Angus, J. (2009). Acoustics and psychoacoustics *Music Technology Series* (2nd ed.). Oxford: Focal Press.

Jenstad, L. M., & Souza, P. E. (2005). Quantifying the effect of compression hearing aid release time on speech acoustics and intelligibility. [Article]. *Journal of Speech Language and Hearing Research, 48*(3), 651-667.

Kaas, J. H., Hackett, T. A., & Tramo, M. J. (1999). Auditory processing in primate cerebral cortex. *Current Opinion in Neurobiology, 9*(164).

Kaernbach, C., & Bering, C. (2001). Exploring the temporal mechanism involved in the pitch of unresolved harmonics. *Journal of the Acoustical Society of America, 110*(2), 1039-1048.

Keidser, G., Dillon, H., & Byrne, D. (1996). Guidelines for fitting multiple memory hearing aids *Journal of the American Academy of Audiology, 7*, 406-418.

Kirk, K. I., Sehgal, M., & Miyamoto, R. T. (1997). Speech perception performance of nucleus multichannel cochlear implant users with partial electrode insertions. *Ear and Hearing, 18*(6), 456-471.

Kistler, M. (2011). Adult Learners: Considerations for Education and Training. *Techniques, 86*(2), 29-30.

Klieve, S., & Jeanes, R. (2001). Perception of prosodic features by children with cochlear implants: is it sufficient for understanding meaning differences in language? *Deafness & Education International, 3*(1), 15-37.

Kochkin, S. (2002). 10-Year Customer Satisfaction Trends in the US Hearing Instrument Market. *Hearing Review, 9*(10), 14-25.

Kong, Y. Y., Cruz, R., Jones, J. A., & Zeng, F. G. (2004a). Music perception with temporal cues in acoustic and electric hearing. *Ear and Hearing, 25*(2), 173-185.

Kong, Y. Y., Stickney, G. S., & Zeng, F. G. (2004b). Speech and melody recognition in binaurally combined acoustic and electric hearing. *Journal of the Acoustical Society of America, 117*(3 Pt 1), 1351-1361.

Kong, Y. Y., Stickney, G. S., & Zeng, F. G. (2005). Speech and melody recognition in binaurally combined acoustic and electric hearing. *Journal of the Acoustical Society of America, 117*(3), 1351-1361.

Kraus, N., McGee, T., Carrell, T., & Sharma, A. (1995). Neurophysiologic bases of speech discrimination. *Ear and Hearing, 16*(19-37).

Kricos, P. B., Holmes, A. E., & Doyle, D. A. (1992). Efficacy of a communication training program for hearing-impaired elderly adults. Journal of the Academy of Rehabilitative Audiology, 25, 69-80.

Lan, N., Nie, K. B., Gao, S. K., & Zeng, F. G. (2004). A novel speech-processing strategy incorporating tonal information for cochlear implants. *IEEE Transactions on Biomedical Engineering, 51*(5), 752-760.

Laneau, J., Wouters, J., & Moonen, M. (2006). Improved music perception with explicit pitch coding in cochlear implants. *Audiology and Neurotology, 11*(1), 38-52.

Laver, J. (1994). *Principles of Phonetics.* Cambridge: Cambridge University Press.

Leal, M. C., Shin, Y. J., Laborde, M. L., Calmels, M. N., Verges, S., Lugardon, S., et al. (2003). Music perception in adult cochlear implant recipients. *Acta Oto-Laryngologica, 123*(7), 826-835.

Leek, M. R., Molis, M. R., Kubli, L. R., & Tufts, J. B. (2008). Enjoyment of music by elderly hearing-impaired listeners. *Journal of the American Academy of Audiology, 19*(6), 519-526.

Lehiste, I., & Peterson, G. E. (1959). Linguistic Considerations in the Study of Speech Intelligibility. *The Acoustical Society of America, 31*(3), 280-286.

Li, M., McAllister, H. G., Black, N. D., & De Perez, T. A. (2001). Perceptual time-frequency subtraction algorithm for noise reduction in hearing aids. *IEEE Transactions on Biomedical Engineering, 48*(9), 979-988.

Limb, C., Molloy, A., Jiradejvong, P., & Braun, A. (2010). Auditory Cortical Activity During Cochlear Implant-Mediated Perception of Spoken Language, Melody, and Rhythm. *Journal of the Association for Research in Otolaryngology, 11*(1), 133-143.

Liu, E. H., Mercado, E., III, Church, B. A., & Orduña, I. (2008). The easy-to-hard effect in human (Homo sapiens) and rat (Rattus norvegicus) auditory identification. *Journal of Comparative Psychology, 122*(2), 132-145.

Loizou, P. (1998). Mimicking the human ear. *IEEE Signal Processing Magazine,* Septermber, 101-130.

Looi, V. (2008b). The effect of cochlear implantation of music: A review. *Otorinolaringologia, 58*(4), 169-190.

Looi, V., McDermott, H., McKay, C., & Hickson, L. (2007). Comparisons of quality ratings for music by cochlear implant and hearing aid users. *Ear and Hearing, 28*(2), 59S-61S.

Looi, V., McDermott, H., McKay, C., & Hickson, L. (2008a). The effect of cochlear implantation on music perception by adults with usable pre-operative acoustic hearing. *International Journal of Audiology, 47*(5), 257-268.

Looi, V., McDermott, H., McKay, C., & Hickson, L. (2008c). Music perception of cochlear implant users compared with that of hearing aid users. *Ear and Hearing, 29*(3), 421-434.

Looi, V., & Radford, C. J. (2011). A comparison of the speech recognition and pitch ranking abilities of children using a unilateral cochlear implant, bimodal stimulation or bilateral hearing aids. *International Journal of Pediatric Otorhinolaryngology, 75*(4), 472-482.

Looi, V., & She, J. (2010b). Music perception of cochlear implant users: A questionnaire, and its implications for a music training program. *International Journal of Audiology, 49*(2), 116-128.

Looi, V., Sucher, C., & McDermott, H. J. (2003). Melodies Familiar to the Australian Population Across a Range of Hearing Abilities. The Australian and New Zealand Journal of Audiology, 25(2), 75-83.

Luo, X., Fu, Q.-J., & Galvin, J. J. (2007). Vocal emotion recognition with cochlear Implants. *Trends in Amplification, 11*(4), 311-315.

Massaro, D. W., Kallman, H. J., & Kelly, J. L. (1980). The role of tone height, melodic contour, and tone chroma in melody recognition. *Journal of Experimental Psychology: Human Learning and Memory, 6*(1), 77-90.

McDermott, H. J. (2004). Music perception with cochlear implants: A review. *Trends In Amplification, 8*(2), 49-82.

McDermott, J. H., & Oxenham, A. J. (2008). Music perception, pitch, and the auditory system. *Current Opinion in Neurobiology, 18*(452-463).

McKay, C. M., McDermott, H. J., & Clark, G. M. (1994). Pitch percepts associated with amplitude-modulated current pulse trains in cochlear implantees. *The Journal of the Acoustical Society of America, 96*(5), 2664-2673.

McKay, C. M., McDermott, H. J., & Clark, G. M. (1995). Pitch matching of amplitude-modulated current pulse trains by cochlear implantees: The effect of modulation depth. *The Journal of the Acoustical Society of America, 97*(3), 1777-1785.

McKay, M. S., & Mateer, C. A. (1989). *Introduction to cognitive rehabilitation: theory and practice*. New York: Guilford Press.

Meddis, R., & Hewitt, M. J. (1991). Virtual pitch and phase sensitivity of a computer model of the auditory periphery. II: Phase sensitivity. *The Journal of the Acoustical Society of America, 89*(6), 2883-2894.

Meister, H., Landwehr, M., Pyschny, V., Walger, M., & Wedel, H. v. (2009). The perception of prosody and speaker gender in normal-hearing listeners and cochlear implant recipients. *International Journal of Audiology, 48*(1), 38-48.

Meyer, M., Alter, K., Friederici, A. D., Lohmann, G., & von Cramon, D. Y. (2002). FMRI reveals brain regions mediating slow prosodic modulations in spoken sentences. Human Brain Mapping, 17(2), 73-88.

Mitani, C., Nakata, T., Trehub, S. E., Kanda, Y., Kumagami, H., Takasaki, K., et al. (2007). Music recognition, music listening, and word recognition by deaf children with cochlear implants *Ear and Hearing, 28*(2), 29S- 33S.

Moore, B., & Glasberg, B. (1988). Difference limens (DLs) for phase in normally hearing subjects and subjects with unilteral cochlear hearing loss. *Journal of the Acoustical Society of America*, *83*(S1), S75-S75.

Moore, B., & Skrodzka, E. (2002). Detection of frequency modulation by hearing-impaired listeners: Effects of carrier frequency, modulation rate, and added amplitude modulation. *Journal of the Acoustical Society of America, 111*(1), 327-335.

Moore, B. C. (1996). Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. *Ear and Hearing, 17*(2), 133-161.

Moore, B. C. J. (2003). Coding of sounds in the auditory system and its relevance to signal processing and coding in cochlear implants. *otolaryngol, Head & Neck Surgery, 24*(2), 243-254.

Moore, B. C., & Carlyon, R. P. (2005). Perception of pitch by people with cochlear hearing loss and by cochlear implant users. In C. J. Plack & A. J. Oxenham (Eds.), *Springer Handbook of Auditory Research: Pitch Perception*. New York: Springer-Verlag.

Moore, B. C., & Moore, G. A. (2003b). Discrimination of the fundamental frequency of complex tones with fixed and shifting spectral envelopes by normally hearing and hearing-impaired subjects. *Hearing Research, 182*(1-2), 153-163.

Moore, B. C., & Peters, R. W. (1992). Pitch discrimination and phase sensitivity in young and elderly subjects and its relationship to frequency selectivity. *Journal of the Acoustical Society of America, 91*(5), 2881-2893.

Moore, B. C. J. (1989). *An introduction to the psychology of hearing* (3rd ed.). London: Academic Press.

Moore, B. C. J. (2007). *Cochlear Hearing Loss: Physiological, Psychological and Technical Issues* (2nd ed.). West Sussex: John Wiley & Sons, Ltd.

Moore, B. C. J., & Skrodzka, E. (2002). Detection of frequency modulation by hearing-impaired listeners: Effects of carrier frequency, modulation rate, and added amplitude modulation. *The Journal of the Acoustical Society of America, 111*(1), 327-335.

Moore, D. R., & Amitay, S. (2007). Auditory training : Rules and applications. *Seminars in Hearing, 28*(2), 99-109.

Moore, G. A., & Moore, B. C. (2003a). Perception of the low pitch of frequency-shifted complexes. *Journal of the Acoustical Society of America, 113*(2), 977-985.

Most, T., & Aviner, C. (2009). Auditory, visual, and auditory-visual perception of emotions by individuals with cochlear implants, hearing aids, and normal hearing. *Journal of Deaf Studies and Deaf Education, 14*(4), 449-464.

Most, T., & Peled, M. (2007). Perception of suprasegmental features of speech by children with cochlear implants and children with hearing aids. *Journal of Deaf Studies and Deaf Education, 12*(3), 350.

Naito, Y., Tateya, I., Fujiki, N., Hirano, S., Ishizu, K., Nagahama, Y., et al. (2000). Increased cortical activation during hearing of speech in cochlear implant users. *Hearing Research, 143*(1-2), 139-146.

Nakata, T., Trehub, S. E., Mitani, C., & Kanda, Y. (2006). Pitch and timing in the songs of deaf children with cochlear implants. *Music Perception: An Interdisciplinary Journal*, *24*(2), 147-154.

Nakata, T., Trehub, S. E., Mitani, C., Kanda, Y., Shibasaki, A., & Schellenberg, E. G. (2005). Music recognition by Japanese children with cochlear implants. *Journal of Physiological Anthropology and Applied Human Science*, *24*(1), 29-32.

Nordrum, S., Erler, S., Garstecki, D., & Dhar, S. (2006). Comparison of Performance on the Hearing in Noise Test Using Directional Microphones and Digital Noise Reduction Algorithms. *American Journal of Audiology, 15*(1), 81-91.

Novick M, Bentler R, Dittberner A, & G., F. (2001). The effects of release time and directionality on unilateral and bilateral hearing aid fittings in complex sound fields. *Journal of the American Academy of Audiology, 12*, 493-504.

O'Donoghue, G. M., Nikolopoulos, T. P., & Archbold, S. M. (2000). Determinants of speech perception in children after cochlear implantation. *The Lancet, 356*(9228), 466-468.

Olszewski, C., Gfeller, K., Froman, R., Stordahl, J., & Tomblin, B. (2006). Familiar melody recognition by children and adults using cochlear implants and normal hearing children. *Cochlear Implants International, 6*, 123-140.

Olsen, A. D. (2010). *Auditory training at home for adult haering aid users.* Unpublished Dissertation, University of Kentucky, Lexington, Kentucky.

Osberger, M., Miyamoto, R., Zimmerman-Phillips, S., Kemink, J., Stroer, B., Firszt, J., et al. (1991). Independent evaluation of the speech perception abilities of children with the Nucleus 22-channel cochlear implant system. *Ear & Hearing, 12 (Suppl),* 66S-80S.

Oxenham, A. J. (2008). Pitch aerception and auditory stream segregation: Implications for hearing loss and cochlear implants. *Trends in Amplification, 12*(4), 316-331.

Oxenham, A. J., Bernstein, J. G., & Penagos, H. (2004). Correct tonotopic representation is necessary for complex pitch perception. *Proceedings of the National Academy of Sciences of the United States of America, 101*(5), 1421-1425.

't Hart, J., Collier, R., & Cohen, A. (1990). *A perceptual study of intonation*. Cambridge, UK: Cambridge University Press.

Peng, S. C., Tomblin, J. B., & Turner, C. W. (2008). Production and perception of speech intonation in pediatric cochlear implant recipients and individuals with normal hearing. *Ear and Hearing, 29*(3), 336-351.

Pereira, C. (1996, 10-12 December). *"Angry, happy, sad or plain neutral? The identification of vocal afect by hearing aid users."* Paper presented at the Proceedings of the Sixth Australian International Conference on Speech Science and Technology, Adelaide.

Pereira, C. (2000a). *Perception and expression of emotion in speech.* Unpublished PhD Thesis, Macquarie Sydney.

Pereira, C. (2000b). *Dimensions of emotional meaning in speech.* Paper presented at the Proceedings of the ISCA Workshop on Speech and Emotion Northern Island.

Peters, K. P. (2006). *Emotion Perception in Speech: Discrimination, Identification and the Effects of Talker and Sentence Variability.* Unpublished Capstone Project, Washington University School of Medicine, Washington.

Pickett, J. M. (1999). *The acoustics of speech communication: Fundamentals, speech perception theory, and echnology.* . Boston: Allyn & Bacon Inc.

Pijl, S. (1997). Labeling of Musical Interval Size by Cochlear Implant Patients and Normally Hearing Subjects. *Ear and Hearing, 18*(5), 364-372.

Pisoni, D. B. (2000). Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear and Hearing, 21*(1), 70-78.

Pissoni, D. B., & Cleary, M. (Eds.). (2004). *Learning, memory, and cognitive processes in deaf children following cochlear implantation.* New York: Springer.

Pizzo, R. G., Garotta, M., Amigoni, E., Ambrosetti, U., & Fagnani, E. (2000). Perceptual and Cognitive Neuroplasiticity in Adults with Cochlear Implants. In S. B.

Waltzman & N. L. Cohen (Eds.), *Cochlear Implants*. New York: Thieme Medical Publishers, Inc.

Ponton, C. W., Moore, J. K., & Eggermont, J. J. (1999). Prolonged deafness limits auditory system developmental plasticity: Evidence from an evoked potentials study in children with cochlear implants. *Scandinavian Audiology supplement*, 13-22.

Psarros, C. E., Plant, K. L., Lee, K., Decker, J. A., Whitford, L. A., & Cowan, R. S. C. (2002). Conversion from the SPEAK to the ACE strategy in children using the nucleus 24 cochlear implant system: speech perception and speech production outcomes. *Ear and Hearing, 23*(1), 18S-27S.

Punch, J. L. (1978). Quality judgments of hearing aid-processed speech and music by normal and otopathologic listeners. *Journal of the AMerican Audiological Society, 3*(4), 179-188.

Pyman, B., Blamey, P., Lacy, P., Clark, G. M., & Dowell, R. (2000). The development of speech perception in children using cochlear implants: effects of etiologic factors and delayed milestones. *The American Journal of Otology 21*(1), 57-61.

Recanzone, G. H., Schreiner, C. E., & Merzenich, M. M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *The Journal of Neuroscience, 13*(1), 87-103.

Revoile, S., Kozma-Spytek, L., Holden-Pitt, L., Pickett, J. M., & Droge, J. (1991). VCVs vs CVCs for stop/fricative distinctions by hearing?impaired and normal?hearing listeners. *Journal of the Acoustical Society of America, 89*(1), 457-460.

Richardson, L. M., Busby, P. A., Blarney, P. J., & Clark, G. M. (1998). Studies of Prosody Perception by Cochlear Implant Patients. *International Journal of Audiology, 37*(4), 231-245.

Ricketts, T., & Mueller, H. G. (1999). Making Sense of Directional Microphone Hearing Aids. *American Journal of Audiology, 8*(2), 117-127.

Rigo, T. G., & Lieberman, D. A. (1989). Nonverbal sensitivity of normal-hearing and hearing-impaired older adults. *Ear and Hearing, 10*(3), 184-189.

Ross, M. (2009). Listening to music through hearing aids the "music" program. *Hearing Loss Magazine, 30*(4), 26.

Roth, D. A., Appelbaum, M., Milo, C., & Kishon-Rabin, L. (2008). Generalization to untrained conditions following training with identical stimuli. *J Basic Clin Physiol Pharmacol, 19*(3-4), 223-236.

Roth, D. A., Rafael-Taub, R., Sharvit, R., & Kishon-Rabin, L. (2006). Can learning a frequency discrimination task occur without discrimination? *J Basic Clin Physiol Pharmacol, 17*(3), 159-171.

Ruggero, M. A. (1994). Cochlear delays and traveling waves: comments on 'Experimental look at cochlear mechanics'. *Audiology, 33*(3), 131-142.

Rutledge, K. L. (2009). A music listening questionnaire for hearing aid users. University of Canterbury.

Scherer, K. R. (1984). On the nature and the function of emotion: A component process approach. In Ekman.P. (Ed.), *Approaches to emotion* (pp. 293-317). Hillsdale, NJ: Erlbuam.

Schon, D., Gordon, R., Campagne, A., Magne, C., Astesano, C., Anton, J. L., et al. (2010). Similar cerebral networks in language, music and song perception. *Neuroimage., 51*(1), 450-461. Epub 2010 Feb 2013.

Schon, D., Magne, C., & Besson, M. (2004). The music of speech: Music training facilitates pitch processing in both music and language. *Psychophysiology, 41*(3), 341-349.

Schorr, E. A., Fox, N. A., & Roth, F. P. (2004). Social and emotional functioning of children with cochlear implants: description of the sample. *International Congress Series, 1273*, 372-375.

Schouten, J. F., Ritsma, R. J., & Cardozo, B. L. (1962). Pitch of the Residue. *The Journal of the Acoustical Society of America, 34*(9B), 1418-1424.

Sehgal, S. T., Kirk, K. I., Svirsky, M., & Miyamoto, R. T. (1998). The effects of processor strategy on the speech perception performance of pediatric nucleus multichannel cochlear implant users. *Ear and Hearing, 19*(2), 149-161.

Sharma, A., Dorman, M. F., & Kral, A. (2005). The influence of a sensitive period on central auditory development in children with unilateral and bilateral cochlear implants. *Hearing Research, 203*, 134-143.

Sharma, A., Dorman, M. F., & Spahr, A. J. (2002). A sensitive period for the development of the central auditory system in children with cochlear implants: Implications for age of implantation. *Ear and Hearing, 23*(6), 564-573.

Shinall, A. R. (2005). *Emotion Perception in Pre-Kindergarten School Children at Central Institute for the Deaf.* Unpublished Independent Study, Washington University School of Medicine, Washington.

Shpak, T., Koren, L., Tzach, N., Most, T., & Luntz, M. (2009). Perception of speech by prelingual pre-adolescent and adolescent cochlear implant users. *International Journal of Audiology, 48*(11), 775-783.

Skinner, M. W., Holden, L. K., Whitford, L. A., Plant, K. L., Psarros, C., & Holden, T. A. (2002). Speech recognition with the nucleus 24 SPEAK, ACE, and CIS speech coding strategies in newly implanted adults. *Ear Hear., 23*(3), 207-223.

Smith, Z., Delgutte, B., & Oxenham, A. J. (2002). Chimaeric sounds reveal dichotomies in auditory perception. *Nature, 416*, 87-90.

Stacey, P. C., Raine, C. H., O'Donoghue, G. M., Tapper, L., Twomey, T., & Summerfield, A. Q. (2010). Effectiveness of computer-based auditory training for adult users of cochlear implants. *International Journal of Audiology, 49*(5), 347-356.

Stalinski, S. M., Schellenberg, E. G., & Trehub, S. E. (2008). Developmental changes in the perception of pitch contour: distinguishing up from down. *Journal of the Acoustical Society of America, 124*(3), 1759-1763.

Stickney, G. S., Zeng, F.-G., Litovsky, R., & Assmann, P. F. (2004). Cochlear implant speech recognition with speech maskers. *Journal of the Acoustical Society of America*, *116*(2), 1081-1091.

Sucher, C. M., & McDermott, H. J. (2007). Pitch ranking of complex tones by normally hearing subjects and cochlear implant users. *Hearing Research, 230*(1-2), 80-87.

Sucher, C. M., & McDermott, H. J. (2009). Bimodal stimulation: benefits for music perception and sound quality. *Cochlear Implants International, 10* (S1), 96–99.

Sussman, E., Winkler, I., Huotilainen, M., Ritter, W., & Näätänen, R. (2002). Top-down effects can modify the initially stimulus-driven auditory organization. *Cognitive Brain Research, 13*(3), 393-405.

Syka, J. (2002). Plastic changes in the central auditory system after hearing loss, restoration of function, and during learning. *Physiological Reviews, 82*(3), 601-636.

Trehub, S. E., Bull, D., & Thorpe, L. A. (1984). Infants' perception of melodies: the role of melodic contour. *Child Development, 55*(3), 821-830.

Tremblay, K. L. (2007). Training-related changes in the brain: evidence from human-auditory evoked potentials. *Seminars in Hearing, 28*(2), 120-132.

Tremblay, K., Kraus, N., Carrell, T. D., & McGee, T. (1997). Central auditory system plasticity: Generalization to novel stimuli following listening training. *Journal of the Acoustical Society of America, 102* (6), 3762-3773.

Trimmer, C. G., & Cuddy, L. L. (2008). Emotional intelligence, not music training, predicts recognition of emotional speech prosody. *Emotion, 8*(6), 838-849.

Tyler, R. S., Fryauf-Bertschy, H., Kelsay, D. M., Gantz, B. J., Woodworth, G. P., & Parkinson, A. (1997). Speech perception by prelingually deaf children using cochlear implants. *Otolaryngology-Head and Neck Surgery 117*(3), 1.

Tyler, R. S., Witt, S., Dunn, C. C., & Wang, W. (2010). Initial development of a spatially separated speech-in-noise and localization training program. *Journal of the American Academy of Audiology, 21*, 390-403.

Vandali, A. E., Whitford, L. A., Plant, K. L., & Clark, G. M. (2000). Speech perception as a function of electrical stimulation rate: using the Nucleus 24 cochlear implant system. *Ear and Hearing, 21*(6), 608-624.

Vinay, & Moore, B. C. J. (2007). Speech recognition as a function of high-pass filter cutoff frequency for people with and without low-frequency cochlear dead regions. *The Journal of the Acoustical Society of America, 122*(1), 542-553.

Vongpaisal, T., Trehub, S. E., & Schellenberg, E. G. (2006). Song Recognition by Children and Adolescents With Cochlear Implants. *Journal of Speech, Language, and Hearing Research, 49*(5), 1091-1103.

Vongpaisal, T., Trehub, S. E., & Schellenberg, E. G. (2009). Identification of TV Tunes by Children with Cochlear Implants. *Music Perception: An Interdisciplinary Journal, 27*(1), 17-24.

Walden, B. E., Erdman, S. A., Montgomery, A. A., Schwartz, D. M., & Prosek, R. A. (1981). Some Effects of Training on Speech Recognition by Hearing-Impaired Adults. *Journal of Speech and Hearing Research, 24*(2), 207-216.

Walker-Andrews, A. S., & Lennon, E. (1991). Infants' discrimination of vocal expressions: Contributions of auditory and visual information. *Infant Behavior and Development, 14*(2), 131-142.

Ward, W. D. (1954). Subjective musical pitch. *Journal of the Acoustical Society of America*, *26*, 369-380.

Wawroski, L. R. (2008). *Speech Recognition in Noise and Intonation Recognition in Primary-School-Aged Children, and Preliminary Results in Children with Cochlear Implants.* Unpublished Dissertation University of Maryland, College Park, Md.

Wei, C.-G., Cao, K., & Zeng, F.-G. (2004). Mandarin tone recognition in cochlear-implant subjects. *Hearing Research, 197*(1-2), 87-95.

Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., et al. (1993). Modulation of early sensory processing in human auditory cortex during auditory selective attention. *Proceedings of the National Academy of Sciences of the United States, 90*(18),

Woods, D. L., & Yund, E. W. (2007). Perceptual training of phoneme identification for hearing loss. *Seminars in Hearing, 28*(2), 110-119.

Woolf, N. K., Ryan, A. F., & Bone, R. C. (1981). Neural phase-locking properties in the absence of cochlear outer hair cells. *Hearing Research, 4*, 335-346.

Wouters, J., & Vanden Berghe, J. (2001). Speech recognition in noise for cochlear implantees with a two- microphone monaural adaptive noise reduction system. *Ear & Hearing, 22,* 420-430.

Wu, J. L., Yang, H. M., Lin, Y. H., & Fu, Q. J. (2007). Effects of computer-assisted speech training on Mandarin-speaking hearing-impaired children. *Audiology and Neuro-Otology, 12*(5), 307-312.

Xu, L., Li, Y., Hao, J., Chen, X., Xue, S. A., & Han, D. (2004). Tone production with Mandarin–Speaking children with cochlear implants: A preliminary study. *Acta Oto-Laryngologica, 124*, 363-367.

Yost, W. (2007). *Fundamentals of hearing: An introduction* (5th ed.). San Diego, CA, USA: Academic Press.

Yucel, E., Sennaroglu, G., & Belgin, E. (2009). The family oriented musical training for children with cochlear implants: Speech and musical perception results of two year follow-up. *International Journal of Pediatric Otorhinolaryngology, 73*(7), 1043-1052.

Yund, E. W., & Buckles, K. M. (1995). Enhanced speech perception at low signal-to-noise ratios with multichannel compression hearing aids. *Journal of the Acoustical Society of America, 97*(2), 1224-1240.

Zeng, F.-G. (2002). Temporal pitch in electric hearing. *Hearing Research, 174*(1-2), 101-106.

Zeng, F.-G. (2004). Trends in Cochlear Implants. *Trends in Amplification, 8*(1), 1-34.

Appendix 1. A Sample Invitation Letter Sent to the Participants.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

2 April 2010

Dear Sir/Madam

My name is Dona Jayakody. I am a doctoral student in Audiology at University of Canterbury, Christchurch, New Zealand.

As part of my studies, I have developed a "Pitch-perception training program" with the aim of training pitch perception of hearing impaired individuals. It is a computer-based program that you complete at home at times that suits you. The purpose of this letter is to seek participants to take part of this study, and I hope that you are willing to donate some of your time for this interesting study.

Enclosed is an information sheet, which describes the study, a consent form, and a pre-training questionnaire. Should you be able to take part in the study, please sign the consent form, fill in the attached questionnaires, and return both in the postage paid envelope. If you could please return the replies to me by 25 April 2010, I'd appreciate it.

A petrol voucher will be provided to assist with your travel costs to attend the test sessions. The testing conducted in this study is separate to any testing conducted as a part of your cochlear implantation process/or habilitation process. You will also be able to keep the training program at the conclusion of the study.

Should you have any queries regarding the study, and your role in it, please do not hesitate to contact me at dmp64@student.canterbury.ac.nz (land line: 364 2987 ext 8465, mobile +64 210569096) or my supervisor Dr. Valerie Looi at Valerie.looi@canterbury.ac.nz (phone: +64 3 364 2987 ext 3051).

I hope that you will be able to participate in this interesting study, and I look forward for your reply.

Thank you in advance for your time.

Yours Sincerely,
Dona Jayakody

Appendix 2. A Sample Information Sheet Sent to the Participants.

THE UNIVERSITY OF CANTERBURY

Department of Communication Disorders

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

INFORMATION FOR SUBJECTS PARTICIPATING IN RESEARCH

A Computerized Pitch-Perception Training Program for the Hearing Impaired (CI-Adults)

Principal Investigator: Dona Jayakody Email: dmp64@student.canterbury.ac.nz Phone: +64 3 3642987 Ext. 8465 Mobile: +64 210569096 Fax: +64 3 364 2760	c/o Department of Communication Disorders University Of Canterbury Private Bag 4800 Christchurch 8020
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INTRODUCTION

You are invited to participate in a research project. In this study, we are investigating ways of improving speech, and music perception for hearing impaired adults and children who use cochlear implants (CIs) or hearing aids (HAs). Your participation in this study is entirely voluntary, and if you choose not to take part, your choice will not affect any current or future care or treatment. You are free to withdraw from the study at any time, without having to give any reason. This will in no way affect your future care.

AIMS OF RESEARCH:

The aim of this study is to develop an effective pitch-perception training program, and subsequently pilot test this program with adults using CIs or HAs and children using CIs. The training program aims to find out whether pitch-perception training can improve:

Appendix 2 continued. (A Sample Information Sheet Sent to the Participants).

1. Understanding of speech in noisy backgrounds.
2. Identification of familiar melodies.
3. Identification of familiar musical instruments.
4. Identification of utterances as questions or statements.
5. Identification of emotions expressed in speech.

INCLUSION CRITERIA:

Subjects involved in the study must meet the following criteria:

- Speak English as their first language and native speakers of NZ English or have been speaking NZ English for more than 10 years;
- Above 18 years of age;
- Have been using a CI for more than 1 year;
- No other major impairment i.e., cognitive, neurological, visual or significant physical impairment that would impede the use of the training program;
- Access to a computer at their home/ or willingness to travel to the University of Canterbury 4 times a week for a period of 10 weeks to take part in the training program.

DESCRIPTION OF THE PROCEDURE:

Prior to the first session, you will be asked to fill out a "familiar melody and musical instrument identification" questionnaire to find out information regarding melodies, and the musical instruments that are familiar to you. You will randomly be assigned to either a **control** or to **training** group.

If you are in the control group, you will have to attend two sessions, which are approximately 12 weeks apart.

Procedure for the control group

- Session 1: This will take approximately 1.5-2 hours. In this session you will be required to undertake the following tasks.

1. **Speech perception tests**- you will be asked to listen to a set of pre-recorded words or sentences and repeat them.
2. **Pitch perception test**- you will be asked to listen to pairs of two tones and select the tone that sounds "higher" in pitch.
3. **Familiar melody and instrument identification tests**- you will be asked to listen to a set of randomly selected excerpts of melodies and instrumental recordings, and identify them.
4. **Emotion identification test**- you will be asked to listen to a set of pre-recorded sentences and select the underlying emotions of the utterances as "happy", "sad", "neutral" or "angry".
5. **Question/Statement identification tests**- you will be asked to listen to a set of pre-recorded sentences and identify them as either a "question", or "statement".

Appendix 2 continued. (A Sample Information Sheet Sent to the Participants).

You will also be asked to complete a questionnaire about your musical background; you can take this questionnaire home to complete if you prefer.

- Session 2: In this session similar set of tests from session 1 will be re-administered. This will take approximately 1.5-2 hours. After completing the second test session, you will be given an opportunity to undertake the training program, if you wish.

Procedures for training group

If you fall into the training group, you will have to attend three sessions.

- Session 1: This will take approximately 2 hours. In this session you will be required to undertake the following tasks.

6. **Speech perception tests**- you will be asked to listen to a set of pre-recorded words or sentences and repeat them.
7. **Pitch perception test**- you will be asked to listen to pairs of two tones and select the tone that sounds "higher" in pitch.
8. **Familiar melody and instrument identification tests**- you will be asked to listen to a set of randomly selected excerpts of melodies and instrumental recordings, and identify them.
9. **Emotion identification test**- you will be asked to listen to a set of pre-recorded sentences and select the underlying emotions of the utterances as "happy", "sad", "neutral" or "angry".
10. **Question/Statement identification test**- you will be asked to listen to a set of pre-recorded sentences and identify them as either a "question", or a "statement".

- Session 2: You will be given a demonstration of the computer based training program. This will take approximately 1 hour. You will be asked to use the training program 30 minutes, 4 times a week for a period of 10 weeks. Support will be available to you throughout the study.

- Session 3: This will be held after you complete the 10 –week training program, and this will take approximately 2 hours. In this session, a similar set of tests from session 1 will be re-administered. You will be asked to complete a questionnaire about your opinion of the training program.

DETAILS OF THE TRAINING PROGRAM:

This training program is implemented as a computer based program with interactive activities progressing from simple to complex tasks. It incorporates a large number of musical instruments and voices for you to choose from. This will provide you with an opportunity to be trained on a variety of natural stimuli and to individualize the training to suit your preferences. The training will automatically adjust the difficulty level depending on your needs and responses. Support will be available to your throughout the training. A written instruction manual is also included with the program.

Appendix 2 continued. (A Sample Information Sheet Sent to the Participants).

The program has the following general structure:

(1) explanation of the program, its goals, and the musical terms used in the program,

(2) pitch ranking tasks to select the tone with a higher/lower pitch,

(3) identifying odd-ball stimuli (i.e. the tone with a different pitch in a sequence), and

(4) pitch-sequence training with 9 melodic contours (i.e., direction of melody as ascending vs. descending).

For each response you will be given a visual feedback. You will also be able to select instruments of your choice for training tasks.

POSSIBLE BENEFITS OF THE TRAINING PROGRAM:

We hope that by completing the training program, you will be able to improve your pitch perception skills. This may also generalize to improved speech perception in noise, and greater music appreciation. Results obtained from this training program will be used to help in counseling new & potential CI recipients & HA users, it potentially could also provide better outcomes and greater enjoyment for listening to music which is related to quality of life, and the benefits of improved pitch perception may generalize to improved emotion identification & speech perception in noise. In addition, this training program may be used in the future as a part of an aural rehabilitation training program to improve music perception in CI and HA users.

POSSIBLE RISKS:

The risks associated with this research are no different to those that you would expect in everyday use of your CI, or attending a hearing test at an audiology clinic. However, support will be available throughout your involvement with the study. All the stimuli will be presented at your comfortable listening levels. All the testing will be carried out by a qualified audiologist. Your participation is entirely voluntarily and you can withdraw yourself from the study at any time.

CONFIDENTIALITY:

All data collected will be stored according to current University of Canterbury Speech and Hearing Clinic protocols. Any personal information will be retained in a secure filing system or on password protected computer, to which only the personnel directly involved in the project will have access. No material which could personally identify you will be used in any reports on this study. At the completion of the study, any data required to be kept will be stored securely. Any data not required will be destroyed. Should you withdraw yourself from the study any of your data collected will be withdrawn and destroyed.

Appendix 2 continued. (A Sample Information Sheet Sent to the Participants).

COMPLETION OF THE STUDY:

It is anticipated that this study will be completed by the end of December 2010. Copies of your personal results for this study can be provided to you if requested. Any research published in scientific or clinical journals, or presented at national or international conferences is also available to you should you be interested.

ETHICAL APPROVAL:

This study has received ethical approval from the Upper South B Regional Ethics Committee(ethics reference number URB/09/09/043), and the University of Canterbury Human Ethics Committee.

If you have any concerns in regards to any aspect of this research, please do not hesitate to contact me (Dona Jayakody). Should you have any complaints, you are free to contact myself, or the Primary Supervisor (Valerie Looi).

If you have concerns regarding your rights as a participant in this study, you may also wish to contact an independent Health and Disability Advocate:

South Island: 0800 377 766

Fax: 0800 2787 7678

E-mail: advocacy@hdc.org.nz

Appendix 3. A Sample Consent Form Sent to the Participants.

THE UNIVERSITY OF CANTERBURY

Department of Communication Disorders

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

CONSENT FORM FOR SUBJECTS PARTICIPATING IN RESEARCH

A Computerized Pitch-Perception Training Program for the Hearing Impaired (CI-Adults)

Principal Investigator: Dona Jayakody Email: dmp64@student.canterbury.ac.nz Phone: +64 3 3642987 Ext. 8465 Mobile: +64 210569096 Fax: +64 3 364 2760	c/o Department of Communication Disorders University Of Canterbury Private Bag 4800 Christchurch 8020
Primary Supervisor: Dr Valerie Looi Email: Valerie.looi@canterbury.ac.nz Phone: +64 3364 2987 Ext 3051	

CONSENT STATEMENT

- I have read and understood the information sheet for the study called: "A computerized pitch-perception training program for hearing impaired".
- I have had the opportunity to ask questions, regarding this study and I am satisfied with the answers that I have been given.
- I have had the opportunity to use whanau support or a friend to help me ask questions and understand the study.
- I understand that taking part in this study is entirely voluntary, and I can withdraw myself at any stage during the research without affecting any current or future care or treatment. Any of my data collected prior to this withdrawal will be removed and destroyed.

Appendix 3 continued. (A Sample Consent Form Sent to the Participants)

- I consent to researchers directly involved in this study contacting the SCIP, and accessing my audiological files kept at their audiology clinic.

- I understand that my participation in this study is confidential and that no material which could identify me will be provided to public or used in any reports, publications, or presentations on this study.
- I have had the time to consider whether to take part.
- I know whom to contact if I have any questions about the study.

I...(Full name) hereby consent to take part in this study. **Phone:** ....(Home)............................(work) **Mobile:** .... **Fax :** .... **Address:** .... **Email:** ....
Consent to release Audiological and Otolaryngology Records
I consent to letting researchers access my Audiological and Otolaryngological files for the purpose of this study.

Please return in the postage paid envelope provided before (25 March, 2010)

If you **DO NOT** wish to participate in this study, please indicate this below, and return to us in the envelope provided. This enables us to track replies received, so we do not re-contact you.

I <u>do not</u> wish to take part in the study. Name______________________________ Signed____________________

Appendix 4. Musical Background Questionnaire - Adult CI Recipients.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Musical Background Questionnaire: Adult CI Recipients

NAME:... DATE: ....

DATE OF BIRTH: .... GENDER: Male ☐ Female ☐

DEVICE INFORMATION

DATE OF SURGERY: .... EAR IMPLANTED: Left ☐ Right ☐

IMPLANT MODEL: .... PROCESSOR MODEL: ....

Do you use your cochlear implant every day? Yes ☐ No ☐

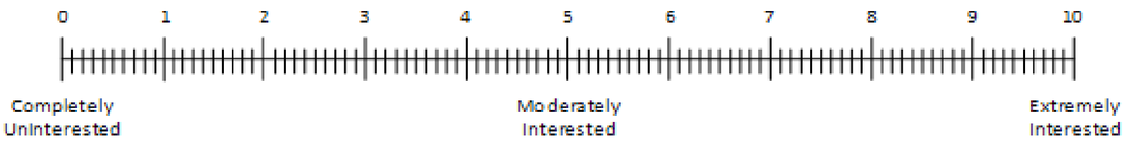
How many hours a day do you wear your implant? ....

Do you wear a hearing aid in your non-implanted ear? Yes ☐ No ☐

If yes, how many hours do you wear your hearing aid each day? ....

MUSICAL ENJOYMENT & PARTICIPATION

1. On a scale of 0 to 10, where do you rate your personal interest in music? Please mark the scale below using an 'X' to indicate where your level of interest rests.



Appendix 4 continued. (Musical Background Questionnaire - Adult CI Recipients)

2. On a scale of 0 to 10, where do you rate your current level of musical enjoyment? Please mark the scale below using an 'X' to indicate where your level of enjoyment rests.

0 1 2 3 4 5 6 7 8 9 10

No Enjoyment — Moderate Level of Enjoyment — High Level of Enjoyment

3. Which of the following genres of music do you enjoy listening to?

	Prior to Implantation / before your hearing loss	After Implantation
None	☐	☐
Classical: Instrumental	☐	☐
Classical: Vocal	☐	☐
Country	☐	☐
Easy Listening	☐	☐
Electronic / Techno	☐	☐
Folk	☐	☐
Hard Rock	☐	☐
Jazz	☐	☐
Pop / Rock	☐	☐
Religious (Hymns, Gospel)	☐	☐
Rhythm & Blues	☐	☐

Appendix 4 continued. (Musical Background Questionnaire - Adult CI Recipients)

	Prior to Implantation / before your hearing loss	After Implantation
Other (please specify below)	☐	☐

4. Have you received **formal** musical training? Yes ☐ No ☐

If *yes*, please complete the following as applicable. If *no*, please go on to question 5.

Activity	Training in: (i.e. piano, or classical singing, or music history)	Age Lessons Received (i.e. 8 - 12 years of age)	Duration of Formal Training (Years)	Highest Grade Level Completed
Learning A Musical Instrument	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
Singing	....	....	....	....
	....	....	....	....
Music Theory	....	....	....	....
	....	....	....	....
	....	....	....	....
Music Classes	....	....	....	At School
	....	....	....	At University
	....	....	....	At Adult College

....	....	....	Other: ....

5. Have you ever participated in any of the following musical activities? Yes ☐ No ☐

If *yes* please complete the sections relevant to you. If *no*, please move onto question 6.

Activity	**Age at which you started participating**	**Number of years of Involvement**
Orchestra	....	....
Band	....	....
Choir	....	....
Musical Theatre	....	....

6. Have you ever been involved in **informal** musical activities? Yes ☐ No ☐

If *yes* please describe the activity/activities in the space provided below, (i.e. learned to play guitar by ear, with friends etc).

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Appendix 4 continued. (Musical Background Questionnaire - Adult CI Recipients)

7. When listening through your cochlear implant, please indicate how often you can identify the following sounds by hearing alone (i.e. without visual cues)?

	Never	Sometimes	Often	Very Often	Always
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Speaker from Background Noise	☐	☐	☐	☐	☐
Singer from Background Music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

Appendix 4 continued. (Musical Background Questionnaire - Adult CI Recipients)

8. Please rank your level of participation in the following musical activities.

Activity	Before your Hearing Loss (if applicable) / Before implantation: None	Monthly	Weekly	Daily	After Implantation: None	Monthly	Weekly	Daily
Solo singing	☐	☐	☐	☐	☐	☐	☐	☐
Group singing/Choir	☐	☐	☐	☐	☐	☐	☐	☐
Musical theatre	☐	☐	☐	☐	☐	☐	☐	☐
Playing/learning an instrument	☐	☐	☐	☐	☐	☐	☐	☐
Learning / playing instrument in a small group	☐	☐	☐	☐	☐	☐	☐	☐
Attending musical concerts	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded speech (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded music (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Music Theory Classes	☐	☐	☐	☐	☐	☐	☐	☐
Reading about music history	☐	☐	☐	☐	☐	☐	☐	☐

If you are currently taking part in any music related activities please skip question 9 and move on to question 10.

Appendix 4 continued. (Musical Background Questionnaire - Adult CI Recipients)

9. If you are not currently participating in any music related activities after receiving your implant please indicate which (if any) of the following statements describe your reasons for not taking part.

Music doesn't seem pleasant through the implant ☐

I don't enjoy listening to music anymore ☐

I don't have time to listen to music anymore ☐

I have never been interested in music ☐

Other (please specify below) ☐

....

....

....

10. Please select the statement that best describes any change in your enjoyment of music in the time since you received your cochlear implant.

"Since receiving my cochlear implant I…

...haven't noticed any changes in my enjoyment of music." ☐

...have started to dislike musical sounds/ music." ☐

...continue to enjoy listening to music at a level that is similar to before I received my implant." ☐

...am more interested in music." ☐

...custom response (please specify):..

....

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....

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 5. Musical Background Questionnaire - Adult Hearing Aid Users.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Musical Background Questionnaire: Adult Hearing Aid Users

NAME:.. DATE:...

DATE OF BIRTH: .... GENDER: Male ☐ Female ☐

TYPE OF HEARING LOSS: .... (L EAR).. (R EAR)

TYPE OF HEARING AIDS USED .... (L) ....(R)

DURATION OF HEARING AID USE (YEARS)....................................... (L) ....(R)

Do you use your hearing aids every day? Yes ☐ No ☐

If yes, how many hours do you wear your hearing aids each day? ....

MUSICAL ENJOYMENT & PARTICIPATION

1. On a scale of 0 to 10, where do you rate your personal interest in music? Please mark the scale below using an 'X' to indicate where your level of interest rests.

0 1 2 3 4 5 6 7 8 9 10

Completely Uninterested — Moderately Interested — Extremely Interested

2. On a scale of 0 to 10, where do you rate your current level of musical enjoyment? Please mark the scale below using an 'X' to indicate where your level of enjoyment rests.

0 1 2 3 4 5 6 7 8 9 10

No Enjoyment — Moderate Level of Enjoyment — High Level of Enjoyment

Appendix 5 continued. (Musical Background Questionnaire - Adult Hearing Aid Users)

3. Which of the following genres of music do you enjoy listening to?

	Before your hearing loss	With your Hearing Aids
None	☐	☐
Classical: Instrumental	☐	☐
Classical: Vocal	☐	☐
Country	☐	☐
Easy Listening	☐	☐
Electronic / Techno	☐	☐
Folk	☐	☐
Hard Rock	☐	☐
Jazz	☐	☐
Pop / Rock	☐	☐
Religious (Hymns, Gospel)	☐	☐
Rhythm & Blues	☐	☐
Other (please specify below)	☐	☐

....

....

Appendix 5 continued. (Musical Background Questionnaire - Adult Hearing Aid Users)

4. Have you received **formal** musical training? Yes ☐ No ☐

If *yes*, please complete the following as applicable. If *no*, please go on to question 5.

Activity	Training in: (i.e. piano, or classical singing, or music history)	Age Lessons Received (i.e. 8 - 12 years of age)	Duration of Formal Training (Years)	Highest Grade Level Completed
Learning A Musical Instrument	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
Singing	....	....	....	....
	....	....	....	....
Music Theory	....	....	....	....
	....	....	....	....
	....	....	....	....
Music Classes	....	....	....	At School
	....	....	....	At University
	....	....	....	At Adult College
	....	....	....	Other: ....

Appendix 5 continued. **(**Musical Background Questionnaire - Adult Hearing Aid Users)

5. Have you ever participated in any of the following musical activities? Yes ☐ No ☐

If *yes* please complete the sections relevant to you. If *no*, please move onto question 6.

Activity	**Age at which you started participating**	**Number of years of Involvement**
Orchestra	....	....
Band	....	....
Choir	....	....
Musical Theatre	....	....

6. Have you ever been involved in **informal** musical activities? Yes ☐ No ☐

If *yes* please describe the activity/activities in the space provided below, (i.e. learned to play guitar by ear, with friends etc).

....

....

....

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....

Appendix 5 continued. (Musical Background Questionnaire - Adult Hearing Aid Users)

7. When listening through your hearing aids, please indicate how often you can identify the following sounds by hearing alone (i.e. without visual cues)?

	Never	Sometimes	Often	Very Often	Always
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Speaker from Background Noise	☐	☐	☐	☐	☐
Singer from Background Music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

Appendix 5 continued. (Musical Background Questionnaire - Adult Hearing Aid Users)

8. Please rank your level of participation in the following musical activities.

	Before your Hearing Loss				With your Hearing Aids			
Activity	**None**	**Monthly**	**Weekly**	**Daily**	**None**	**Monthly**	**Weekly**	**Daily**
Solo singing	☐	☐	☐	☐	☐	☐	☐	☐
Group singing/Choir	☐	☐	☐	☐	☐	☐	☐	☐
Musical theatre	☐	☐	☐	☐	☐	☐	☐	☐
Playing/learning an instrument	☐	☐	☐	☐	☐	☐	☐	☐
Learning / playing instrument in a small group	☐	☐	☐	☐	☐	☐	☐	☐
Attending musical concerts	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded speech (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded music (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Music Theory Classes	☐	☐	☐	☐	☐	☐	☐	☐
Reading about music history	☐	☐	☐	☐	☐	☐	☐	☐

If you are currently taking part in any music related activities please skip question 9 and move on to question 10.

Appendix 5 continued. (Musical Background Questionnaire - Adult Hearing Aid Users)

9. If you are not currently participating in any music related activities since you started using your hearing aids please indicate which (if any) of the following statements describe your reasons for not taking part.

Music doesn't seem pleasant through my hearing aids ☐

I don't enjoy listening to music anymore ☐

I don't have time to listen to music anymore ☐

I have never been interested in music ☐

Other (please specify below) ☐

....

....

....

10. Please select the statement that best describes any change in your enjoyment of music in the time since you received your hearing aids.

"Since receiving my hearing aids I...

...haven't noticed any changes in my enjoyment of music." ☐

...have started to dislike musical sounds/ music." ☐

..continue to enjoy listening to music at a level that is similar to before I received my hearing aids." ☐

...am more interested in music." ☐

...custom response (please specify):...

....

....

....

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

PLEASE RETURN THE COMPLETED QUESTIONNAIRE TO THE FOLLOWING ADDRESS USING THE INCLUDED PREPAID ENVELOPE

Dona Jayakody, c/o Department of Communication Disorders

The University of Canterbury, Private Bag 4800, Christchurch 8020

Appendix 6. Musical Background Questionnaire - Pediatric CI Recipients.

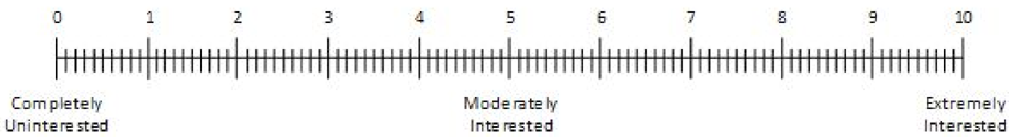
THE UNIVERSITY OF CANTERBURY:

DEPARTMENT OF COMMUNICATION DISORDERS

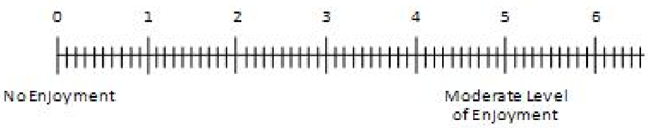
Musical Background Questionnaire: Pediatric CI Recipients

NAME: .... DATE: ....

1. On a scale of 0 to 10, where do you rate your interest in music? Please mark the scale below using an 'X' to indicate where your level of interest rests.



2. On a scale of 0 to 10, where do you rate your current level of musical enjoyment? Please mark the scale below using an 'X' to indicate where your level of enjoyment rests.



3. Name **five** of your favourite songs:

1 ....

2 ....

3 ....

Appendix 6 continued. (Musical Background Questionnaire - Pediatric CI Recipients)

4.…………………………………………………………………………

5.……………………………………………………………………………

…………………………………………………………………………………………

4. Can you always identify these songs/tunes when you hear them played? (even if there are no visual cues such as pictures on TV, CD covers) Yes ☐ No ☐

5 Can you recognise when your favourite TV show is on just by hearing the theme song? (you are unable to see the picture) Yes ☐ No ☐

6. Which of the following styles of music do you enjoy listening to?

None	☐
Classical: Instrumental	☐
Classical: Vocal	☐
Country	☐
Easy Listening	☐
Electronic / Techno	☐
Folk	☐
Hard Rock	☐
Jazz	☐
Pop / Rock	☐
Religious (Hymns, Gospel)	☐
Rhythm & Blues	☐
Other (please specify below)	☐

……………………………………………………………

……………………………………………………………

7. Do you have a favourite singer, instrumentalist or a band?

If you answered **Yes**, what are your favourite artist(s)/band(s) names?

……

……

Appendix 6 continued. (Musical Background Questionnaire - Pediatric CI Recipients)

8. How often do you do the following activities?

ACTIVITY	Every Day	Every Other Day	Once A Week	Once a Fortnight	Once a Month	Once every Few Months	Less than Once A Year	Never
Watch Music Shows on TV/DVD/Video	☐	☐	☐	☐	☐	☐	☐	☐
Dance to Music	☐	☐	☐	☐	☐	☐	☐	☐
Sing along to Music	☐	☐	☐	☐	☐	☐	☐	☐
Play an Instrument	☐	☐	☐	☐	☐	☐	☐	☐
Go to musical concerts	☐	☐	☐	☐	☐	☐	☐	☐
Buy Music CDs / MP3s / DVDs	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded music (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Write Songs	☐	☐	☐	☐	☐	☐	☐	☐
Read Music Magazines	☐	☐	☐	☐	☐	☐	☐	☐
Share music with Friends	☐	☐	☐	☐	☐	☐	☐	☐

Appendix 6 continued. (Musical Background Questionnaire - Pediatric CI Recipients)

9. When listening with your CI, have you noticed any changes in the way that music sounds over the years? Please select the appropriate answer for you.

Music sounds a lot worse than before	☐
Music sounds worse than before	☐
I haven't noticed any change in the way that music sounds	☐
Music sounds better than before	☐
Music sounds a lot better than before	☐

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 7. Musical Background Questionnaire - Parents of Pediatric CI Recipients.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Musical Background Questionnaire: Parents of Pediatric CI Users

PARENT/CARE GIVER NAME:.. DATE: ....

CHILD NAME:..

DATE OF BIRTH: .... GENDER: Male ☐ Female ☐

DEVICE INFORMATION

DATE OF SURGERY: .... EAR IMPLANTED: Left ☐ Right ☐

IMPLANT MODEL: .... PROCESSOR MODEL: ....

Does your child use his/her cochlear implant every day? Yes ☐ No ☐

How many hours a day does your child wear his/her implant? ....

Does your child wear a hearing aid in his/her non-implanted ear? Yes ☐ No ☐

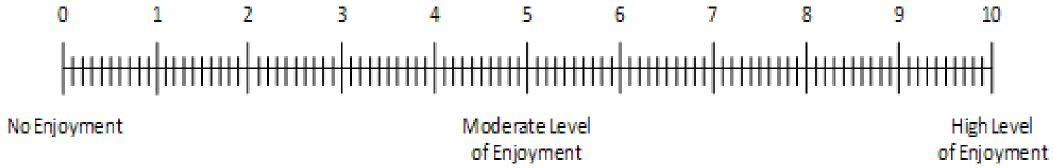
If yes, how many hours would your child wear his/her hearing aid each day? ....

MUSICAL ENJOYMENT & PARTICIPATION

1. On a scale of 0 to 10, where do you rate your child's interest in music? Please mark the scale below using an 'X' to indicate where your child's level of interest rests.

Appendix 7 continued. (Musical Background Questionnaire - Parents of Pediatric CI Recipients)

2. On a scale of 0 to 10, where do you rate your child's current level of musical enjoyment? Please mark the scale below using an 'X' to indicate where his/her level of enjoyment rests.



3. Have your child received **formal** musical training? Yes ☐ No ☐

If *yes*, please complete the following as applicable. If *no*, please go on to question 5.

Activity	Training in: (i.e. piano, or classical singing, or music history)	Age Lessons Received (i.e. 8 - 12 years of age)	Duration of Formal Training (Years)	Highest Grade Level Completed
Learning A Musical Instrument	....	....	....	....
	....	....	....	....
	....	....	....	....
	....	....	....	....
Singing	....	....	....	....
	....	....	....	....
Music Theory	....	....	....	....
	....	....	....	....

Appendix 7 continued. (Musical Background Questionnaire - Parents of Pediatric CI Recipients)

Music Classes				
	....	....	....	At School
	....	....	....	At University
	....	....	....	At Adult College
	....	....	....	Other: ....

4. Does your child participate in any **informal** musical activities? Yes ☐ No ☐

If *yes* please describe the activity/activities in the space provided below, (i.e. learned to play guitar by ear, with friends etc).

If yes, please complete the sections relevant to your child. If no, please move in to question 5.

....

....

....

....

....

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....

....

....

....

Appendix 7 continued. (Musical Background Questionnaire - Parents of Pediatric CI Recipients)

5. When listening through his/her CI, please indicate how often you think your child can identify the following sounds by hearing alone (i.e. without visual cues)?

	Never	Sometimes	Often	Very Often	Always
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Speaker from Background Noise	☐	☐	☐	☐	☐
Singer from Background music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

Appendix 7 continued. (Musical Background Questionnaire - Parents of Pediatric CI Recipients)

6. Please rank your child's level of participation in the following musical activities.

	Before receiving CI, with Hearing Aids				With her/his CIs			
Activity	**None**	**Monthly**	**Weekly**	**Daily**	**None**	**Monthly**	**Weekly**	**Daily**
Solo singing	☐	☐	☐	☐	☐	☐	☐	☐
Group singing/Choir	☐	☐	☐	☐	☐	☐	☐	☐
Musical theatre	☐	☐	☐	☐	☐	☐	☐	☐
Playing/learning an instrument	☐	☐	☐	☐	☐	☐	☐	☐
Learning / playing instrument in a small group	☐	☐	☐	☐	☐	☐	☐	☐
Attending musical concerts	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded speech (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Listening to live or recorded music (Radio/CD/iPod)	☐	☐	☐	☐	☐	☐	☐	☐
Music Theory Classes	☐	☐	☐	☐	☐	☐	☐	☐
Reading about music history	☐	☐	☐	☐	☐	☐	☐	☐

*Tick the adjacent box if your child is too young to take part in these activities before implantation.

Appendix 7 continued. (Musical Background Questionnaire - Parents of Pediatric CI Recipients)

7. Does your child attend **formal** musical activities at school? Yes ☐ No ☐

If you answered yes,
How many hours per week, does he/she attend music lessons? ....

How many years does your child has been attending music lessons? ....

If you answered No, please select the reasons why your child has not been attending music lessons at school (please tick all the apply)

School does not have music programs ☐

My child does not want to attend music lessons ☐

CI rehabilitation team think that child is not be ready for music lessons ☐

I don't feel that my child is ready to attend music lessons ☐

Teachers feel that my child is not ready to attend music lessons ☐

My child's time table does not match with the time given for music lessons ☐

Music time has been used for other activities ☐

Financially difficult to afford music lessons ☐

Other reasons(please specify below)

....

....

....

....

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 8. Familiar Melody Identification Questionnaire.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Familiar Melody Identification Questionnaire

NAME:..DATE OF BIRTH...............................

PRIMARY LISTENING DEVICE(S): .... (i.e. Cochlear Implant / Hearing Aids)

The following is a list of songs, some of which may be familiar to you. To help us individualise the music training program to best suit your preferences, please indicate which songs you are familiar with by ticking the appropriate box. If you are familiar with a song, please indicate whether are able to recognise it by ear, and/or sing it in your head.

	I do not recognize this song	I could recognize this song upon hearing it	I can sing this song in my head
1. Amazing Grace	☐	☐	☐
2. Auld Lang Syne	☐	☐	☐
3. Away in a Manger	☐	☐	☐
4. Baa Baa Black Sheep	☐	☐	☐
5. Danny boy	☐	☐	☐
6. Do Re Mi (from the Sound of Music)	☐	☐	☐

Appendix 8 continued. (Familiar Melody Identification Questionnaire**)**

	I do not recognize this song	I could recognize this song upon hearing it	I can sing this song in my head
7. Don't Dream It's Over	☐	☐	☐
8. Follow the Yellow Brick Road	☐	☐	☐
9. For He's a Jolly Good Fellow	☐	☐	☐
10. God Defend New Zealand (National Anthem)	☐	☐	☐
11. Green sleeves	☐	☐	☐
12. Happy Birthday	☐	☐	☐
13. Hound Dog (You Ain't Nothing but a...)	☐	☐	☐
14. I Got You (...Babe)	☐	☐	☐
15. Wedding March (Here Comes the Bride)	☐	☐	☐
16. Here We Go around the Mulberry Bush	☐	☐	☐
17. Humpty Dumpty	☐	☐	☐
18. Insy Winsy Spider	☐	☐	☐
19. Imagine	☐	☐	☐

Appendix 8 continued. (Familiar Melody Identification Questionnaire**)**

	I do not recognize this song	I could recognize this song upon hearing it	I can sing this song in my head
20. Jingle Bells	☐	☐	☐
21. Let It Be	☐	☐	☐
22. Loyal	☐	☐	☐
23. Mary Had a Little Lamb	☐	☐	☐
24. Oh Come All Ye Faithful	☐	☐	☐
25. Old MacDonald	☐	☐	☐
26. Pōkare kare ana	☐	☐	☐
27. Puff the Magic Dragon	☐	☐	☐
28. Raindrops Keep Falling on My Head	☐	☐	☐
29. Rock a Bye Baby	☐	☐	☐
30. Rudolf the Red-nosed Reindeer	☐	☐	☐
31. Six Months in a Leaky Boat	☐	☐	☐
32. She'll be Coming 'Round the Mountain	☐	☐	☐

Appendix 8 continued. (Familiar Melody Identification Questionnaire)

	I do not recognize this song	I could recognize this song upon hearing it	I can sing this song in my head
33. Silent Night	☐	☐	☐
34. Slice of Heaven	☐	☐	☐
35. The Sound of Music (The Hills are Alive with...)	☐	☐	☐
36. The Road to Tipperary	☐	☐	☐
37. Twelve Days of Christmas	☐	☐	☐
38. The Wheels of the Bus (...go 'Round & Round)	☐	☐	☐
39. There's a Hole in My Bucket	☐	☐	☐
40. Three Blind Mice	☐	☐	☐
41. Twinkle Twinkle Little Stars	☐	☐	☐
42. When the Saints Go Marching in	☐	☐	☐
43. Yankee Doodle Dandy	☐	☐	☐
44. You are My Sunshine	☐	☐	☐

Appendix 8 continued. (Familiar Melody Identification Questionnaire)

If there are songs that aren't on this list, but you think would be familiar to New Zealand listeners, please list the song title(s) and artist(s):

....

....

....

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

PLEASE RETURN THE COMPLETED QUESTIONNAIRE TO THE FOLLOWING ADDRESS USING THE INCLUDED PREPAID ENVELOPE

Dona Jayakody, c/o Department of Communication Disorders

The University of Canterbury, Private Bag 4800, Christchurch 8020

Appendix 9. Familiar Musical Instrument Identification Questionnaire.

THE UNIVERSITY OF CANTERBURY:

DEPARTMENT OF COMMUNICATION DISORDERS

Familiar Musical Instrument Identification Questionnaire

NAME:...DATE OF BIRTH:.............................

PRIMARY LISTENING DEVICE(S):.. (i.e. Cochlear Implant / Hearing Aids)

Please indicate which of the following musical instruments you are familiar with, ***and*** whether you are able to recognise the instrument when you hear someone playing it. This information will be used to help us individualise the music training program to meet your preferences.

	I am not familiar with this instrument	I am familiar with this instrument	I can recognize this instrument upon hearing it
1. Piano	☐	☐	☐
2. Church Organ	☐	☐	☐
3. Guitar	☐	☐	☐
4. Cello	☐	☐	☐
5. Violin	☐	☐	☐
6. Trumpet	☐	☐	☐
7. Marimba	☐	☐	☐

Appendix 9 continued. (Familiar Musical Instrument Identification Questionnaire.)

	I am not familiar with this instrument	I am familiar with this instrument	I can recognize this instrument upon hearing it
8. Glockenspiel	☐	☐	☐
9. Flute	☐	☐	☐
10. Bass-Clarinet	☐	☐	☐
11. Treble-Clarinet	☐	☐	☐
12. Baritone-Saxophone	☐	☐	☐
13. Tenor-Saxophone	☐	☐	☐
14. Soprano-Saxophone	☐	☐	☐

If there are instruments that aren't on this list, but you can recognise through your normal listening device(s) familiar please list them below:

....

....

....

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

PLEASE RETURN THE COMPLETED QUESTIONNAIRE TO THE FOLLOWING ADDRESS USING THE INCLUDED PREPAID ENVELOPE

Dona Jayakody, c/o Department of Communication Disorders

The University of Canterbury, Private Bag 4800, Christchurch 8020

Appendix 10. Frequency Ranges for Musical Instruments and Sung Vowels.

FREQUENCY RANGES FOR MUSICAL INSTRUMENTS AND SUNG VOWELS

Category	Name	Lowest note	Hz	Highest Note	Hz
Female Sung Vowels	AA	F3	174.61	G#5	830.61
	AE	F3	174.61	G#5	830.61
	EE	F3	174.61	A #5	880.00
	OO	F3	174.61	A5	932.33
	UU	F3	174.61	C#6	1108.73
Male Sung Vowels	AA	C3	130.81	D#4	311.13
	AE	C3	130.81	D#4	311.13
	EE	C3	130.81	D#4	311.13
	OO	C3	130.81	D#4	311.13
	UU	C3	130.81	D#4	311.13
String	Violin	A#3	233.08	C6	1046.5
	Cello	C2	65.41	C6	1046.5
	Guitar	E2	82.41	C6	1046.5
Woodwind	Clarinet (Soprano)	D3	146.83	C6	1046.5
	Clarinet (Bass)	F#2	92.5	D3	146.83
	Saxophone (Soprano)	G#3	207.65	B5	987.77
	Saxophone (Tenor)	G#2	103.83	D#5	622.25
	Saxophone (Baritone)	C2	65.41	F#4	369.99
	Flute	D#4	311.13	C7	2093.00
Keyboard	Piano	C2	65.41	F#5	739.99
	Church Organ	C3	130.81	D6	1174.66
Percussion	Glockenspiel	F5	698.46	D8	4698.64
Brass	Trumpet	F3	174.61	A#5	932.33

Appendix 11. Post-Training Evaluation Questionnaire - Adults with CI/HAs.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Post Training Evaluation Questionnaire: Adults with CI/HAs

NAME: .... DATE: ....

Please fill out the questionnaire regarding your participation in the music training program. Your views of the pitch perception training program are important to us, and will help us to improve it for future use.

1. Did you find this training program beneficial? Yes ☐ No ☐

   If your answer is YES, rank the activities in the order of benefit.

   (1= I feel this activity helped me to improve my pitch perception **the most**;

   2= I feel this activity **least** helped me to improve my pitch perception)

   - Pitch Ranking
   - Odd-one out
   - Melodic Contours

Appendix 11 continued. (Post-Training Evaluation Questionnaire - Adults with CI/HAs)

3. Following questions will help us understand your views of the training program. Please tick the appropriate answer.

ACTIVITY	Very Poor	Poor	Neutral	Good	Very Good
1. Usefulness of the training program	☐	☐	☐	☐	☐
2. Variety of tasks	☐	☐	☐	☐	☐
3. Ease of understanding instructions	☐	☐	☐	☐	☐
4. Ease of following instructions	☐	☐	☐	☐	☐
5. Ease of understanding the training manual	☐	☐	☐	☐	☐
6. Pictures used in the training program	☐	☐	☐	☐	☐
7. Variety of musical instruments	☐	☐	☐	☐	☐
8. Support provided during training	☐	☐	☐	☐	☐
9. Your overall opinion of the training program	☐	☐	☐	☐	☐

Appendix 11 continued. (Post-Training Evaluation Questionnaire - Adults with CI/HAs)

4. How often did you undertake the training program? Please select the appropriate answer.

Once a week	☐
Twice a week	☐
Three times a week	☐
Four times a week	☐
More than four times a week	☐

5. Approximately how much time did you spend on the training program each time?__________________________minutes.

6. What are your views of the duration and the frequency of the training program?

ACTIVITY	Too short	Short	Neutral	Long	Too long
10-week training program	☐	☐	☐	☐	☐
30-minute session	☐	☐	☐	☐	☐
4 sessions per week	☐	☐	☐	☐	☐

Appendix 11 continued. (Post-Training Evaluation Questionnaire - Adults with CI/HAs)

7. Do you have any suggestions to make this training program more enjoyable?

COMPONENT	COMMENT
Task	
• Pitch Ranking	
• Odd-one out	
• Melodic contours	
Duration of the training program	
• 10-weeks	
• 4 sessions per week	
Frequency of the training program	
• 4-sessions per week	
Instructions	
Manual	
Feedback	
Choice of instruments	
Ease of using the program	
Visuals used in the program	
Additional suggestions	

Appendix 11 continued. (Post-Training Evaluation Questionnaire - Adults with CI/HAs)

8. Do you think this training program helped you to improve understanding of following sounds (i.e. without visual cues)?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Singer from Background Noise	☐	☐	☐	☐	☐
Speaker from Background Music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 12. Post-Training Evaluation Questionnaire - Pediatric CI Recipients.

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Post-Training Evaluation Questionnaire: Pediatric Cochlear Implant Recipients

NAME:... DATE: ....

Please help your child fill out the questionnaire regarding his/her participation in the music training program. Your child's views of the pitch perception training program are important to us, and will help us to improve it for future use.

1. Did you find this training program beneficial? Yes ☐ No ☐

If your answer is YES, rank the activities in the order of benefit.

(1= I feel this activity helped me to improve my pitch perception **the most**;

2= I feel this activity **least** helped me to improve my pitch perception)

- Pitch Ranking
- Odd-one out
- Melodic Contours

Appendix 12 continued. (Post-Training Evaluation Questionnaire - Pediatric CI Recipients)

3. Following questions will help us understand your views of the training program. Please tick the appropriate answer.

ACTIVITY	Very Poor	Poor	Neutral	Good	Very Good
1. Usefulness of the training program	☐	☐	☐	☐	☐
2. Variety of tasks	☐	☐	☐	☐	☐
3. Ease of understanding instructions	☐	☐	☐	☐	☐
4. Ease of following instructions	☐	☐	☐	☐	☐
5. Ease of understanding the training manual	☐	☐	☐	☐	☐
6. Pictures used in the training program	☐	☐	☐	☐	☐
7. Variety of musical instruments	☐	☐	☐	☐	☐
8. Support provided during training	☐	☐	☐	☐	☐
9. Your overall opinion of the training program	☐	☐	☐	☐	☐

Appendix 12 continued. (Post-Training Evaluation Questionnaire - Pediatric CI Recipients)

4. How often did you undertake the training program? Please select the appropriate answer.

Once a week	☐
Twice a week	☐
Three times a week	☐
Four times a week	☐
More than four times a week	☐

5. Approximately how much time did you spend on the training program each time?________________________minutes.

6. What are your views of the duration and the frequency of the training program?

ACTIVITY	Too short	Short	Neutral	Long	Too long
10-week training program	☐	☐	☐	☐	☐
30-minute session	☐	☐	☐	☐	☐
4 sessions per week	☐	☐	☐	☐	☐

Appendix 12 continued. (Post-Training Evaluation Questionnaire - Pediatric CI Recipients)

7. Do you have any suggestions to make this training program more enjoyable?

COMPONENT	COMMENT
Task	
• Pitch Ranking	
• Odd-one out	
• Melodic contours	
Duration of the training program	
• 10-weeks	
• 4 sessions per week	
Frequency of the training program	
• 4-sessions per week	
Instructions	
Manual	
Feedback	
Choice of instruments	
Ease of using the program	
Visuals used in the program	
Additional suggestions	

Appendix 12 continued. (Post-Training Evaluation Questionnaire - Pediatric CI Recipients)

8. Do you think this training program helped you to improve understanding of following sounds (i.e. without visual cues)?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Singer from Background Noise	☐	☐	☐	☐	☐
Speaker from Background Music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 13. Questionnaire to Evaluate the Efficacy of the Training Program - Parents of Pediatric CI Recipients

THE UNIVERSITY OF CANTERBURY:
DEPARTMENT OF COMMUNICATION DISORDERS

Questionnaire to Evaluate the Efficacy of the Training Program : Parents of Pediatric Cochlear Implant Users

NAME: .... DATE: ....

Please fill out the questionnaire regarding your child's participation in the music training program. Your views of the pitch perception training program are important to us, and will help us to improve it for future use.

1. Did you find this training program beneficial for your child? Yes ☐ No ☐

   If your answer is YES, rank the activities in the order of benefit.

   (1= I feel this activity helped my child to improve his/her pitch perception **the most**;

   2= I feel this activity **least** helped my child to improve his/her pitch perception)

   - Pitch Ranking
   - Odd-one out
   - Melodic Contours

Appendix 13 continued. (Questionnaire to Evaluate the Efficacy of the Training Program - Parents of Pediatric CI Recipients)

3. Following questions will help us understand your views of the training program. Please tick the appropriate answer.

ACTIVITY	Very Poor	Poor	Neutral	Good	Very Good
1. Usefulness of the training program	☐	☐	☐	☐	☐
2. Variety of tasks	☐	☐	☐	☐	☐
3. Ease of understanding instructions	☐	☐	☐	☐	☐
4. Ease of following instructions	☐	☐	☐	☐	☐
5. Ease of understanding the training manual	☐	☐	☐	☐	☐
6. Pictures used in the training program	☐	☐	☐	☐	☐
7. Variety of musical instruments	☐	☐	☐	☐	☐
8. Support provided during training	☐	☐	☐	☐	☐
9. Your overall opinion of the training program	☐	☐	☐	☐	☐

Appendix 13 continued. (Questionnaire to Evaluate the Efficacy of the Training Program - Parents of Pediatric CI Recipients)

4. How often did your child undertake the training program? Please select the appropriate answer.

Once a week	☐
Twice a week	☐
Three times a week	☐
Four times a week	☐
More than four times a week	☐

5. Approximately how much time did your child spend on the training program each time?__________________________minutes.

6. What are your views of the duration and the frequency of the training program?

Activity	Too short	Short	Neutral	Long	Too long
10-week training program	☐	☐	☐	☐	☐
30-minute session	☐	☐	☐	☐	☐
4 sessions per week	☐	☐	☐	☐	☐

Appendix 13 continued. (Questionnaire to Evaluate the Efficacy of the Training Program - Parents of Pediatric CI Recipients)

7. Do you have any suggestions to make this training program more enjoyable?

COMPONENT	COMMENT
Task	
• Pitch Ranking	
• Odd-one out	
• Melodic contours	
Duration of the training program	
• 10-weeks	
• 4 sessions per week	
Frequency of the training program	
• 4-sessions per week	
Instructions	
Manual	
Feedback	
Choice of instruments	
Ease of using the program	
Visuals used in the program	
Additional suggestions	

Appendix 13 continued. (Questionnaire to Evaluate the Efficacy of the Training Program - Parents of Pediatric CI Recipients)

8. Do you think this training program helped your child to improve understanding of following sounds (i.e. without visual cues)?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Male Speaker	☐	☐	☐	☐	☐
Male Singer	☐	☐	☐	☐	☐
Female Speaker	☐	☐	☐	☐	☐
Female Singer	☐	☐	☐	☐	☐
Singer from Background Noise	☐	☐	☐	☐	☐
Speaker from Background Music	☐	☐	☐	☐	☐
Different talkers speaking at the same time	☐	☐	☐	☐	☐
Different singers singing at the same time	☐	☐	☐	☐	☐
Distinguishing between a question and a statement	☐	☐	☐	☐	☐
Identifying familiar melodies/tunes	☐	☐	☐	☐	☐
Emotions embedded in speech (i.e. whether a speaker is angry/sad/neutral or happy, only by listening to their voice)	☐	☐	☐	☐	☐

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix 14. Analysis of Pitch Ranking Test Scores at

Individual Semitone Separation Levels

I. Analysis 1:

a. Analysis Method: The binomial test was used to determine whether a score obtained from a forced choice task is higher than the score at the 50% chance level. The z score is computed from the formula:

$$z = \frac{\frac{X}{n} - p}{\sqrt{\frac{pq}{n}}}$$

Where:

X = raw score (i.e., number of correct answers)

n = number of observations

p = probability of the choice = 0.5 (because the choice is dichotomous)

q = probability of the alternative choice = 0.5

If z is greater than or equal to 1.64 (one-tailed at 0.05 level) or 1.96 (one-tailed at 0.025 significance level), the score is considered significantly different from chance.

b. Observations:

1. **Baseline measures:** As shown in Table A, the NHA, NHC, and NHC groups performed higher than the 50% chance level at all semitone separation levels for the pre-training PR tests while the CIC group consistently failed to perform significantly above chance with stimuli at 5 semitones apart or lower.
2. **Comparison between pre- and post-training scores:** The PR test scores for the training and control groups before and after training with either V1T or V2T are shown in Table B. As shown in Table B, a significant improvement after training can be observed at some semitone separation levels for all training groups except for the CIC-T1 group.

II. Analysis 2:

a. Analysis method: To improve the statistical power, the V1T and V2T groups were combined to evaluate the training effect in general (see Table C). In addition, an investigation on the adjusted scores was also conducted and results were shown in Table D.

Adjusted score =

number of correct items – (number of incorrect items)/(number of choices-1)

This adjustment will correct for the "guessing" effect. In the pitch ranking test, there are only two choices in each question; therefore, the adjusted score in our case is simply

number of correct items – number of incorrect items

(e.g. the CIC HA group had a total of 32 correct out of 34 items. The adjusted score was then 30 (32-2 = 30).

The rest of the calculation for the significance test remains the same.

b. Observations with the V1T and V2T data combined: A visual inspection of Tables C and D revealed that the adjusted scores showed a slightly clearer picture of the training effect.

HA: A significant improvement was found at 7 semitone separation levels for the HA group whether or not the score was unadjusted (10, 9, 8, 7, 6, 3, 1; see Table C) or adjusted (10, 9, 8, 7, 6, 3, 1; see Table D). But with the adjusted scores, the number of levels at which the score was found significantly above chance increased from 8 to 11 (an increase of 3; See Table D). Results from the unadjusted scores did not show any pre- and post-training difference in the number of semitone separation levels at which the score was significantly above chance (pre: 12 levels, post: 12 levels; see Table C).

CIA: A significant improvement was found at 7 semitone separation levels for the CIA group whether or not the score was unadjusted (12, 11, 10, 8, 5, 4, 2; see Table C) or adjusted (12, 11, 10, 8, 7, 5, 2; See Table D). But with the adjusted scores, the number of levels at which the score was significantly above chance increased from 2 to 5 (an increase of 3; see Table D). Results from the unadjusted scores only showed an increase of 1 (pre: 9 levels, post: 10 levels).

CIC: No significant improvement was found whether or not the scores were adjusted.

Appendix 14 continued. **(**Analysis of Pitch Ranking Test Scores at Individual Semitone Separation Levels)

Table A. Percent-correct scores for the pitch ranking test at different semitone separation levels (i.e., the comparison tones are 12 semitones apart, 11 semitones apart, etc.) for different groups. The baseline measures for the normal hearing (NH) group and three hearing impaired groups (HA, CIA, and CIC) and the three-month-after measures for the NH group (NH-post) were included (n = number of participants).

		Semitone Separation Level											
	n	12	11	10	9	8	7	6	5	4	3	2	1
NHA-pre	19	**100.00***	**97.36***	**94.73***	**97.36***	**97.36***	**97.36**	**94.73***	**92.10***	**89.47***	**89.47***	**89.47***	**89.47***
NHC-pre	12	**100.00***	**95.00***	**100.00***	**100.00***	**95.00***	**95.00***	**100.00***	**100.00***	**90.00***	**85.00***	**95.00***	**90.00***
HA -pre	20	**100.00***	**92.11***	**81.58***	**84.21***	**86.84***	**86.84***	**92.11***	**94.74***	**89.47***	**81.58***	**78.95***	**81.58***
CIA -pre	16	**78.13***	**68.75***	**71.88***	**87.50***	**68.75***	**75.00***	**87.50***	53.13	59.38	**71.88***	53.13	**71.88***
CIC-pre	6	**100.00***	75.00	75.00	**83.33***	66.67	75.00	**83.33***	58.33	58.33	66.67	58.33	50.00

*Significantly better than chance.

Appendix 14 continued. **(**Analysis of Pitch Ranking Test Scores at Individual Semitone Separation Levels)

Table B. Mean percent-correct scores for the pitch ranking test at different semitone separation levels for each of the HA, CIA, and CIC groups before and after V1T or V2T (n = number of participants). Post-training scores significantly different from the pre-training counterparts were underlined.

			Semitone Separation Level											
		n	12	11	10	9	8	7	6	5	4	3	2	1
HA-T1	Pre	10	100.00*	100.00*	80.00*	85.00*	85.00*	80.00*	85.00*	95.00*	85.00*	80.00*	75.00*	65.00
	Post	10	100.00*	95.00*	100.00*	95.00*	95.00*	100.00*	100.00*	95.00*	90.00*	90.00*	80.00*	95.00*
HA-T2	Pre	7	100.00*	85.71*	78.57*	85.71*	85.71*	92.86*	100.00*	100.00*	92.86*	85.71*	78.57*	92.86*
	Post	7	100.00*	100.00*	100.00*	100.00*	100.00*	100.00*	92.86*	85.71*	92.86*	100.00*	85.71*	100.00*
CIA-T1	Pre	8	75.00*	68.75	81.25*	75.00*	62.50	75.00*	93.75*	43.75	62.50	75.00*	56.25	75.00*
	Post	8	87.50*	87.50*	75.00*	56.25	75.00*	75.00*	87.50*	75.00*	68.75	62.50	68.75	56.25
CIA-T2	Pre	8	81.25*	68.75	62.50	100.00*	75.00*	75.00*	81.25*	62.50	56.25	68.75	50.00	68.75
	Post	8	93.76*	75.00*	100.00*	81.25*	93.75*	93.75*	81.25*	81.25*	81.25*	56.25	75.00*	56.25
CIC-T1	Pre	4	100.00*	75.00	62.50	75.00	62.50	62.50	87.50*	50.00	62.50	87.50*	50.00	50.00
	Post	4	75.00	87.50*	75.00	75.00	62.50	75.00	87.50*	62.50	50.00	62.50	62.50	50.00
CIC-T2	Pre	2	100.00*	75.00	100.00*	100.00*	75.00	100.00*	75.00	75.00	50.00	25.00	75.00	50.00
	Post	2	100.00*	75.00	100.00*	75.00	100.00*	75.00	100.00*	75.00	100.00*	25.00	50.00	75.00

Appendix 14 continued. (Analysis of Pitch Ranking Test Scores at Individual Semitone Separation Levels)

Table C. Mean percent-correct scores for the pitch ranking test at different semitone difference levels (i.e., the comparison tones are 12 semitones apart, 11 semitones apart, etc.) for different groups. The baseline measures for the normal hearing (NH) group and three hearing impaired groups (HA, CIA, and CIC) and the three-month-after measures for the NH group (NH-post) were included (n = number of participants).

			Semitone Difference Level											
		n	12	11	10	9	8	7	6	5	4	3	2	1
HA	Pre	17	**100.00***	**94.12***	**79.42***	**85.29***	**85.29***	**85.29***	**91.18***	**97.06***	**88.24***	**82.35***	**76.47***	**76.47***
	Post	17	**100.00***	**97.06***	**100.00***	**97.06***	**97.06***	**100.00***	**97.06***	**91.18***	**91.18***	**94.12***	**82.35***	**97.06***
CIA	Pre	16	**78.13***	**68.75***	**71.88***	**87.50***	**68.75***	**75.00***	**87.50***	53.13	59.38	**71.88***	53.13	**71.88***
	Post	16	**90.63***	**81.25***	**87.50***	**68.75****	**84.38***	**84.38***	**84.38***	**78.13***	**75.00***	59.38	**71.88***	56.25
CIC	Pre	6	**100.00***	75.00	75.00	**83.33***	66.67	75.00	**83.33***	58.33	58.33	66.67	58.33	50.00
	Post	6	**83.33***	**83.33***	**83.33***	75.00	75.00	75.00	**91.67***	66.67	66.67	50.00	58.33	58.33

Appendix 14 continued. (Analysis of Pitch Ranking Test Scores at Individual Semitone Separation Levels)

Table D. Adjusted mean percent-correct scores for the pitch ranking test at different semitone difference levels (i.e., the comparison tones are 12 semitones apart, 11 semitones apart, etc.) for the three hearing impaired groups (HA, CIA, and CIC) pre- and post-training.

			Semitone Separation Level											
		n	12	11	10	9	8	7	6	5	4	3	2	1
HA	Pre	17	**100.00***	**88.24***	58.82	**70.59***	**70.59***	**70.59***	**82.35***	**94.12***	**76.48***	64.71	52.94	52.94
	Post	17	**100.00***	**94.12***	**100.00***	**94.12***	**94.12***	**100.00***	**94.12***	**82.35***	**82.35***	**88.24***	64.71	**94.12***
CIA	Pre	16	56.25	37.50	43.75	**75.00***	**37.50**	**50.00**	**75.00***	6.25	18.75	43.75	6.25	43.75
	Post	16	**81.25***	62.50	**75.00***	37.50	**68.75***	**68.75***	**68.75***	56.25	50.00	18.75	43.75	12.50
CIC	Pre	6	**100.00***	50.00	50.00	66.67	33.33	50.00	66.67	16.67	16.67	33.33	16.67	0.00
	Post	6	66.67	66.67	66.67	50.00	50.00	50.00	**83.33***	33.33	33.33	0.00	16.67	16.67